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REVIEW

Honoring Two Decades of Stockpile Stewardship

Also in this issue:

Protein Research Boosts Forensic Science

Designing Aerodynamic SuperTrucks

Nondestructive Surveillance for Weapons Systems



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About the Cover

In the 20 years since it was established, the nation's Stockpile Stewardship and Management Program has served as a highly effective tool for maintaining confidence in the U.S. nuclear deterrent. As the article beginning on p. 6 describes, the cessation of nuclear testing required weapons scientists and engineers to develop and use more advanced nonnuclear experimental and computational capabilities to better understand how materials' aging processes might affect weapons' performance years into the future. Livermore's High Explosives Applications Facility (HEAF) is home to some of the best-equipped high-explosives research and testing laboratories in the world. The image on the cover shows HEAF researchers verifying equipment and diagnostics prior to an energetic materials experiment.



Cover design: Tom Reason; Photography: George A. Kitrinos

About S&TR

At Lawrence Livermore National Laboratory, we focus on science and technology research to ensure our nation's security. We also apply that expertise to solve other important national problems in energy, bioscience, and the environment. *Science & Technology Review* is published eight times a year to communicate, to a broad audience, the Laboratory's scientific and technological accomplishments in fulfilling its primary missions. The publication's goal is to help readers understand these accomplishments and appreciate their value to the individual citizen, the nation, and the world.

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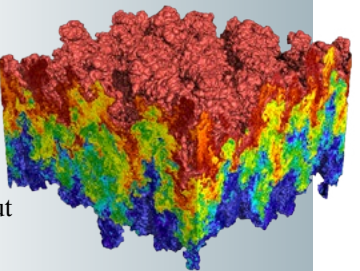
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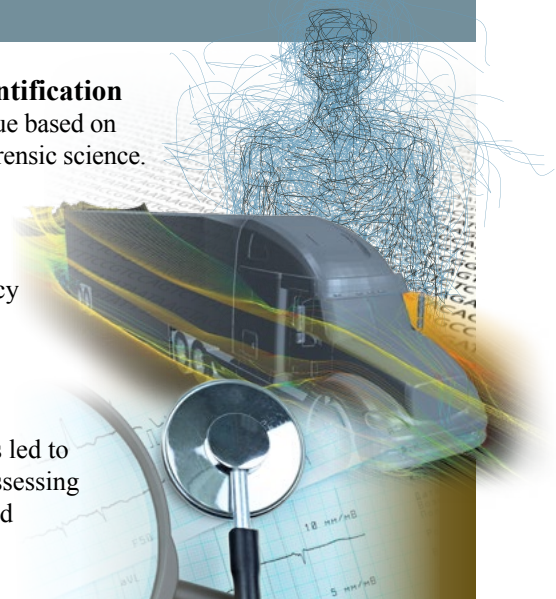


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Graphene Aerogels Improve Energy Storage

A Livermore team has manufactured a new type of graphene aerogel microlattice with an engineered architecture via a three-dimensional (3D) printing technique known as direct-ink writing. The graphene aerogels are mechanically stiff, lightweight, highly conductive, and extremely compressible (exhibiting up to 90 percent compressive strain) with a large surface area. The research appeared in the April 22, 2015, edition of *Nature Communications*.

For this process, an aqueous graphene oxide suspension and silica filler are combined to form a homogenous, highly viscous ink that is then loaded into a syringe barrel and extruded through a micronozzle to pattern 3D structures (process shown at right). Previous attempts at creating bulk graphene aerogels produced a largely random pore structure, which prevented researchers' ability to tailor the transport and other mechanical properties of the material for specific applications such as batteries and pressure sensors.

"Making graphene aerogels with tailored macroarchitectures using a controllable and scalable assembly method was a significant challenge," says Livermore scientist Marcus Worsley, who co-authored the paper. "Three-dimensional printing allows one to intelligently design the pore structure of the aerogel, permitting control over mass transport and optimization of physical properties, such as stiffness." The new 3D printing technique will enable fabrication of complex aerogel architectures for energy storage applications, sensors, nanoelectronics, and catalysis, among others.

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Thinner Capsules Yield Faster Implosions

Researchers at the National Ignition Facility (NIF) together with collaborators from the Laboratory for Laser Energetics at the University of Rochester, the Massachusetts Institute of Technology Plasma Science and Fusion Center, Los Alamos National Laboratory, and General Atomics have been testing target capsules that are 10 to 15 percent thinner than those used in previous experiments. In a paper published in the April 6, 2015, online edition of *Physical Review Letters*, the team detailed the results of several thin-capsule shots representing different ablator thicknesses.

In inertial confinement fusion experiments, the fusion fuel implodes at a high speed in reaction to the rapid ablation, or blow-off, of the outer layers of the target capsule. However, to reach the conditions needed for ignition, the fuel must implode

symmetrically at a peak velocity of about 350 kilometers per second without producing hydrodynamic instabilities that can dampen the fusion reactions. The team's thin-capsule implosions have demonstrated higher velocity and better symmetry control at lower laser powers and energies than their nominal-thickness counterparts. "Little to no hydrodynamic mix of ablator material into the capsule hot spot was observed," says Tammy Ma, a physicist in the NIF and Photon Science Principal Directorate who co-authored the research paper. The team also achieved higher neutron yield and inferred hot-spot pressure with each of the progressively thinner capsules. Ma says, "This result can be attributed to the gain in velocity due to the thinner ablator."

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Comatose Galaxies Shocked Back to Life

Galaxies are often found in clusters, which contain many "red and dead" members that stopped forming stars in the distant past. An international team of astronomers, including Lawrence Livermore's William Dawson, has discovered that these comatose galaxies can sometimes come back to life. If clusters of galaxies merge, a huge shock wave can drive the birth of a new generation of stars. The research appeared in the April 24, 2015, edition of *Monthly Notices of the Royal Astronomical Society*.

Over billions of years, galaxy clusters build up structure in the universe by merging with adjacent clusters. When this collision happens, a huge release of energy produces a shock wave that travels through the cluster like a tsunami. Until recently, no evidence existed that this process greatly affected the galaxies. However, the team observed the merging galaxy cluster CIZA J2242.8+5301, nicknamed the "Sausage," located 2.3 billion light years away and found that the galaxies in the cluster were revived, forming stars at a tremendous rate. Their research implies that the merger of galaxy clusters has a major affect on star formation, in particular, massive, short-lived stars that explode as supernovae a few million years later.

Every cluster of galaxies in the nearby universe has experienced a series of mergers during its lifetime and thus should have undergone a period of extremely vigorous star production. The challenge is observing these clusters during the brief period when the galaxies are still being affected by the shock. The next step in the team's research is to study if the Sausage cluster is unique and whether these bursts of star formation require very particular conditions. By studying a much bigger sample of galaxies, the team aims to reveal exactly how this process occurs.

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Recalling the Origins of Stockpile Stewardship



C. Bruce Tarter



George H. Miller

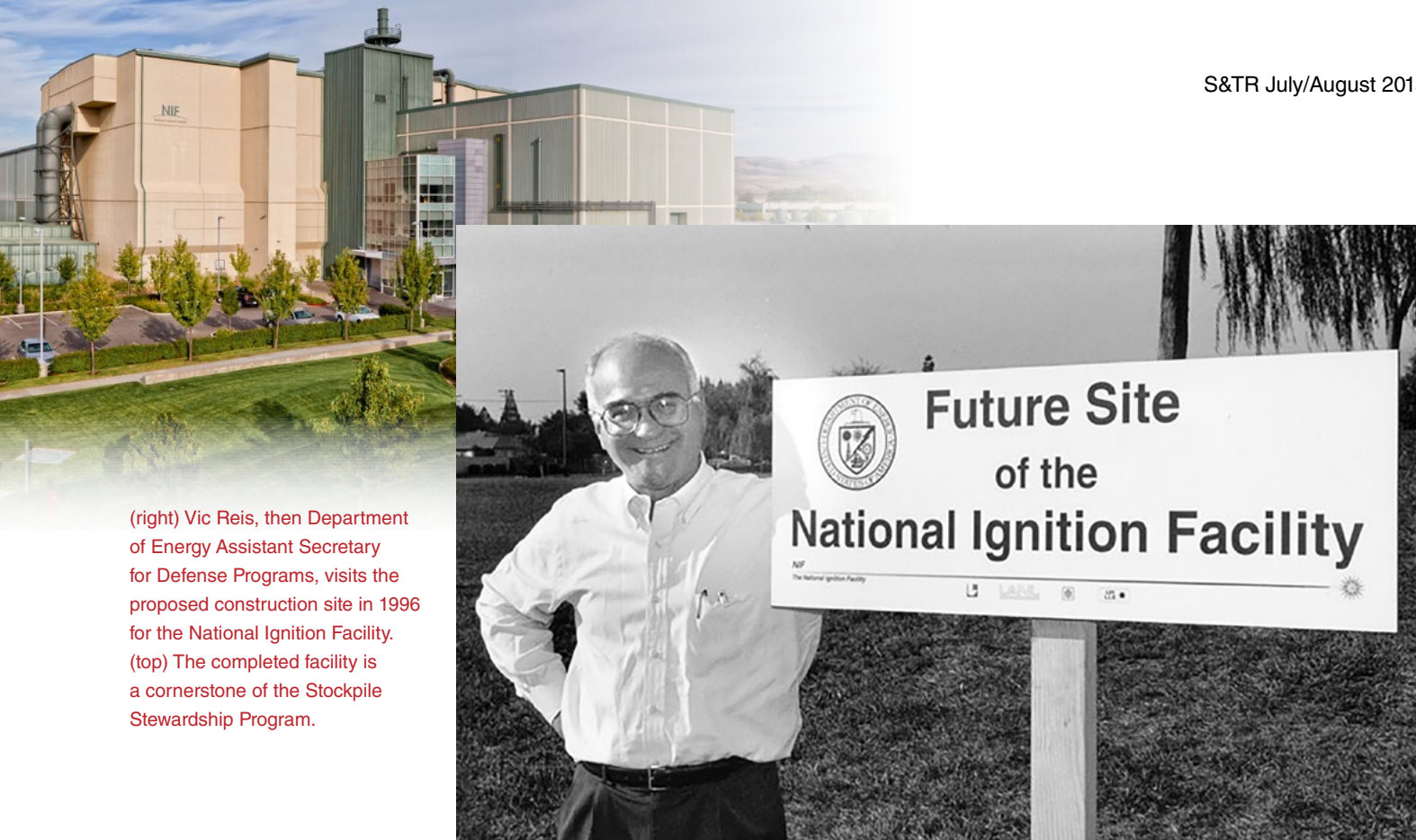
This year marks the 20th anniversary of an ambitious program that transformed how the nation maintains confidence in its nuclear weapons stockpile. Former Laboratory Directors C. Bruce Tarter and George H. Miller were among several Lawrence Livermore managers who played critical roles in helping to define, plan for, and implement the Department of Energy's new Stockpile Stewardship and Management Program. When the program officially began, Tarter was Laboratory director and Miller was associate director for the nuclear weapons program. The following is their recollection of the historic events leading to the adoption of stockpile stewardship.

SEPARATE but related events led to the United States' cessation of nuclear testing and the development of the Stockpile Stewardship and Management Program. The first was the end of the Cold War—the Berlin Wall was destroyed in the fall of 1989 and the Soviet Union formally dissolved on December 8, 1991. In October 1991, the Soviet Union announced a moratorium on nuclear testing, nearly one year after its final test. The United States' last nuclear test was conducted at the Nevada Test Site on September 23, 1992, as the Hatfield-Exon-Mitchell Amendment worked its way through Congress.

Signed into law in October 1992, the new legislation imposed a 9-month moratorium on U.S. nuclear testing and forced significant constraints on any future tests, including a maximum of 15 tests in a 4-year period. The weapons laboratories wanted to explore a wide variety of issues, the Department of Defense (DOD) stressed a

focus on stockpile tests, and Congress emphasized safety. A number of senior-level meetings ensued, including an extensive classified meeting hosted by Department of Energy (DOE) Secretary Hazel O'Leary. I (Miller), then the Laboratory's associate director (AD) for the nuclear weapons program, was the leading technical briefer. The Clinton administration took office in early 1993, extended the testing moratorium, and indicated it would seek a comprehensive test ban to eliminate all future nuclear testing.

Laboratory Director John Nuckolls had already begun preparatory steps in 1991 to develop a strategy for the nuclear weapons program in what looked to be an era of greatly reduced budgets and limited (if any) nuclear testing. My deputy AD, Wayne Shotts, and I were heavily involved in the process, as was Nuckolls' advisory committee, which included luminaries such as Condoleezza Rice, John Deutch, and Johnny Foster.



(right) Vic Reis, then Department of Energy Assistant Secretary for Defense Programs, visits the proposed construction site in 1996 for the National Ignition Facility. (top) The completed facility is a cornerstone of the Stockpile Stewardship Program.

In the spring of 1993, when the Clinton administration's direction on nuclear testing became clearer, a small group—including the two of us, Shotts, Larry Woodruff (former AD for Military Applications), and Bill Lokke (AD for Computation)—held several meetings to lay out a tractable nuclear weapons program for the future. Toward this end, we developed a focused “Letter to the President” that encapsulated our thoughts on the matter.

In general terms, our group accepted the no-testing paradigm, acknowledged the expected decrease in resources (but nothing like what actually occurred), understood the necessity for capturing the archival history and wisdom from weapons scientists and engineers, and realized the importance of laboratory-scale experiments combined with high-performance computing (HPC). Overall, we gained substantial insight into future program scenarios—including the need for a modernized, much smaller production complex—but underestimated how radical a transformation would be required to create a politically and technically acceptable nuclear weapons program. Fortunately, Vic Reis, in his role as the new DOE Assistant Secretary for Defense Programs, provided the imagination and political acumen to guide the transition to what became known as science-based stockpile stewardship.

Reis' genius lay in positing the general solution to the challenge of stockpile stewardship and then working backwards with different groups to acquire their input, gain support, and develop the details of the program. His major premise was that the core of any long-term stewardship program was a set of world-class scientific and technical laboratories with expertise and activities that would ensure their continued competence in all aspects of nuclear weapons. He held a two-day meeting with the weapons and science program leaders from Livermore, Los Alamos, and Sandia national laboratories to develop what the idea meant in practice.

Dick Fortner, then AD for Physics and Space Sciences, and I (Miller) were the two representatives for the Laboratory. The group concluded that the best approach in a non-nuclear-testing environment was a science-based Stockpile Stewardship Program. The goal of the program was to understand the nature of the nuclear explosive process in enough detail to evaluate and fix any problems that would arise during the lifetime of the weapons in the stockpile. Our common vision represented a shift from a nuclear-test-based confidence model to one of validated simulation.

Each of the three weapons laboratories would undertake a major project that was required to strengthen the science base and help

maintain the vitality of the weapons program and the expertise of the people working in it. For Livermore, the project was the National Ignition Facility; for Los Alamos, the Dual-Axis Radiographic Hydrodynamic Test Facility (they would also extend their neutron scattering center to assess the possibility of accelerator production of tritium); and for Sandia, the Microsystems Engineering Sciences Applications Complex. In addition to endorsing and refining the general weapons program outline, the laboratory directors, who were brought into the next iteration of planning, helped achieve concurrence on a price tag of about \$4.5 billion per year for 10 years.

Reis discussed the plan at a major town-hall meeting with more than 100 people from the national security and policy world, including DOD, the National Security Council, the Office of Science and Technology Policy, and academia. Despite some skepticism over the proposed elimination of all testing, the science-based Stockpile Stewardship Program had reasonably broad support, and meeting participants strongly endorsed the need for a major increase in HPC capabilities.

Reis and the senior members of the laboratories spent much of the next year engaging individuals and groups from the town-hall meeting to acquire additional input and gain support for the program. For example, Reis met individually with luminaries such as Harold Brown, James Schlesinger, and Brent Scowcroft; and I (Miller) had numerous discussions with DOD personnel, including an extensive session with U.S. Secretary of Defense Bill Cohen. These activities were vital in developing a broad support base for the future Stockpile Stewardship Program.

The effort reached a pivotal point at the “Confidence Conference” held at Strategic Command in June 1995. The meeting was attended by senior people from DOE and DOD including O’Leary; DOE Undersecretary Charlie Curtis; Reis; the STRATCOM Commander Hank Chiles; and Harold Smith, DOD’s lead official for nuclear matters. The general theme of the conference was whether stockpile confidence could be maintained without nuclear testing, and a particular focus was on the possible role of low-yield nuclear tests. Mike Anastasio, then Livermore’s B-Division leader, gave the principal talk and presented the technical pros and cons for various options. The summary session did not result in consensus, but all the issues were clearly delineated, as were the views of the various participants.

In mid-July the laboratory directors, Curtis, Reis, and Anastasio (the technical briefer), had sequential meetings with General John

Shalikashvili, Chairman of the Joint Chiefs of Staff, and Anthony Lake, the National Security Advisor for President Clinton. As Laboratory director, I (Tarter) attended the meeting with Shalikashvili, which was intense and explored all of the technical and policy matters in depth. Shalikashvili seemed impressed by the level of effort and thoroughness that had gone into planning the Stockpile Stewardship Program. Afterwards, Los Alamos Director Sig Hecker noted the curious fact that among the three laboratory directors and Shalikashvili, I was the only native-born American involved in the conversation.

Early in August, Curtis called each of the laboratory directors individually for a lengthy classified discussion. He wanted to know whether our respective laboratories could accept the challenge of a comprehensive nuclear-test ban and if there were any conditions to such an acceptance. I said that Livermore would welcome the challenge, but I was concerned that the resource level not be reduced and that we be treated on an equal basis with the other two weapons laboratories (in contrast to the recommendation of the Galvin committee). We talked about many other issues, and he thanked me for my input. Incidentally, it was the only time in my career that I entered the Laboratory without a badge. I was called back (to the Laboratory) from a doctor’s appointment and told not to go home first to get my badge—I was just waved through!

On August 11, 1995, President Clinton announced his decision to seek a zero-yield Comprehensive Nuclear-Test-Ban Treaty. An extremely important component of this announcement was his inclusion of six safeguards upon which the treaty was conditioned. The first two safeguards mandated a strong Stockpile Stewardship Program and strong nuclear weapons laboratories and facilities (explicitly mentioning outstanding staff). The next three dealt with readiness, treaty monitoring, and intelligence gathering. The last, known as Safeguard F, spoke to the possibility of failure. It stated that if confidence in the safety or reliability of a weapon type critical to the deterrent could no longer be certified, then the U.S. president would recommend withdrawing from the treaty for the supreme national interest.

On September 25, President Clinton further issued a signed directive stating: “To meet the challenge of ensuring confidence in the safety and reliability of our stockpile, I have concluded that the continued vitality of all three nuclear weapons laboratories will be essential.” At that moment stockpile stewardship was launched, with Livermore as a full partner, and as is often said, the rest has become history.

Stockpile stewardship required more advanced computational capabilities to better understand weapons performance. (right) Construction began on the Livermore Computing Complex in the early 2000s. The facility now houses some of the fastest supercomputers in existence.



Stockpile Stewardship at 20 Years

In the two decades since it was established, the nation's Stockpile Stewardship and Management Program has served as a highly effective tool for maintaining confidence in the U.S. nuclear deterrent.

FOLLOWING the collapse of the Soviet Union and the end of the Cold War, the United States took a series of bold steps to strengthen nuclear nonproliferation. These steps included halting underground nuclear testing, ceasing the development of new nuclear weapons, reducing the size of the existing nuclear stockpile, and beginning to close nonessential elements of the nuclear weapons production complex. In September 1996, President Clinton formally announced his decision to seek a Comprehensive Nuclear-Test-Ban Treaty (CTBT) and directed the Department of Energy (DOE) to take the required actions for sustaining confidence in the stockpile without nuclear testing. Thus, the Stockpile Stewardship and Management Program was formally established to maintain the safety, security, and reliability of the U.S. nuclear deterrent without full-scale testing.

Details of the program were arrived at following months of close consultation between the directors of the three DOE

weapons laboratories (Livermore, Los Alamos, and Sandia national laboratories), DOE officials, and congressional leaders. The new approach relied on advanced scientific understanding through a combination of theoretical advances, nonnuclear (including subcritical) experiments, supercomputer simulations, and enhanced stockpile surveillance—not on additional nuclear testing—to predict, identify, and correct stockpile problems.

A key architect of the fledgling program, DOE's Assistant Secretary for Defense Programs Vic Reis, addressed Livermore employees in October 1995 to discuss the ambitious effort. Reis told employees the "awesome responsibility" for decisions regarding the safety and reliability of the nation's nuclear weapons stockpile "has been put right back where it belongs—with the labs."

The new program posed significant challenges for the DOE weapons laboratories. Weapons typically were

(left) Kevin Vandersall, a researcher in Livermore's High Explosives Applications Facility (HEAF), inspects equipment and diagnostics prior to an energetic materials experiment. HEAF is home to some of the best-equipped high-explosives research and testing laboratories in the world. (Photograph by George A. Kitrinis.) (right) The Laboratory conducted many highly complex underground nuclear tests at the Nevada Test Site (now the Nevada National Security Site) prior to the commencement of the Stockpile Stewardship and Management Program.



designed for a 20-year service life and most often were replaced before then with newer designs. For more than four decades, nuclear testing had provided the means to assure confidence in the stockpile. Bruce Goodwin, associate-director-at-large for Global Security Research, described the challenge as analogous to maintaining a 40-year-old car. “New parts cannot be obtained, and in some cases you can’t make replacement parts because they require materials that are environmentally prohibited or are no longer available,” he says. “You have to ensure that the car runs, but you’re not allowed to start it.” Nevertheless, “it has to work with 100 percent reliability.”

The weapons laboratories now had to understand in far greater detail how materials’ aging processes might affect weapons performance years into the future and to use this information for anticipating when serious issues might initially arise. To succeed in the radically reworked assignment, weapons scientists and engineers required more advanced nonnuclear experimental capabilities. Toward this end, the National Ignition Facility (NIF) was built at Lawrence Livermore, and some of the Laboratory’s other facilities, such as the Contained Firing Facility (CFF) at Site 300 and the High Explosives Applications Facility (HEAF), were significantly upgraded. A series of progressively more powerful supercomputers was also acquired. These computational machines integrated existing nuclear test data and increasing amounts of scientific data on stockpile materials’ performance and aging characteristics. They also served as a surrogate test platform using far more accurate predictive models.

Charlie Verdon, principal associate director for the Weapons and Complex Integration (WCI) Principal Directorate, notes that stockpile stewardship has enabled the three directors of the DOE weapons laboratories—now DOE National Nuclear Security Administration

(NNSA) national security laboratories—to provide the U.S. president an annual assessment of the safety and reliability of the stockpile for more than two decades with no identified need for an underground nuclear test. Verdon says, “This work is a remarkable achievement given the major shift in methods and the many uncertainties at the start of the program.” He notes, however, that the program faces continuing challenges as weapons age.

Enhanced Surveillance

A central focus of the Stockpile Stewardship and Management Program was to enhance routine surveillance of weapons with a combination of predictive aging models and nondestructive testing to forecast and detect age-related material changes at an early stage. For example, plastics break down, metals corrode, and coatings deteriorate in response to long-term exposure to radiation, fluctuating temperatures, and other environmental conditions. Advanced computational models show how materials outgas; polymers slowly change their chemistry; gas bubbles form, grow, and diffuse; explosives recrystallize and interact with binders; materials interact with atmospheric gases, such as water vapor, hydrogen, and oxygen; and how long-term radiation exposure changes materials. (See the article beginning on p. 22.)

Physical chemist Bill McLean, enhanced surveillance campaign manager, says, “With a shrinking stockpile, disassembling and discarding assets to find potential problems is not always practical.” Stockpile stewardship has enabled the development of new nondestructive surveillance technologies to identify potential safety or reliability problems such as corrosion, cracks, and compositional changes without the need for destructive dismantlement.

One important surveillance tool, called CoLOSSIS (Confined Large Optical Scintillator Screen and Imaging System), is

an x-ray computed tomography system to detect aging defects on critical components in nuclear weapons. Developed by Livermore scientists and located at NNSA’s Pantex Plant in Texas, this high-resolution imaging system assembles two-dimensional (2D) digital radiographs into a three-dimensional (3D) tomographic image that scientists analyze to discover any anomalies. Since its installation in 2009, the rate and quality of surveillance efforts have increased dramatically. Researchers are continuing to develop more efficient scintillators for converting x rays to light and to increase the speed of tomographic image reconstruction.

As a complement to existing x-ray diagnostic tools such as CoLOSSIS, Livermore researchers are building a prototype high-energy (10-megaelectronvolt) neutron imaging facility. The machine, scheduled for completion in 2019, is designed to detect cubic-millimeter-scale voids, cracks, and other defects in heavily shielded or low-Z materials such as plastics and polymers. It will be capable of producing 2D radiographic and 3D tomographic images.

Plutonium Aging Gracefully

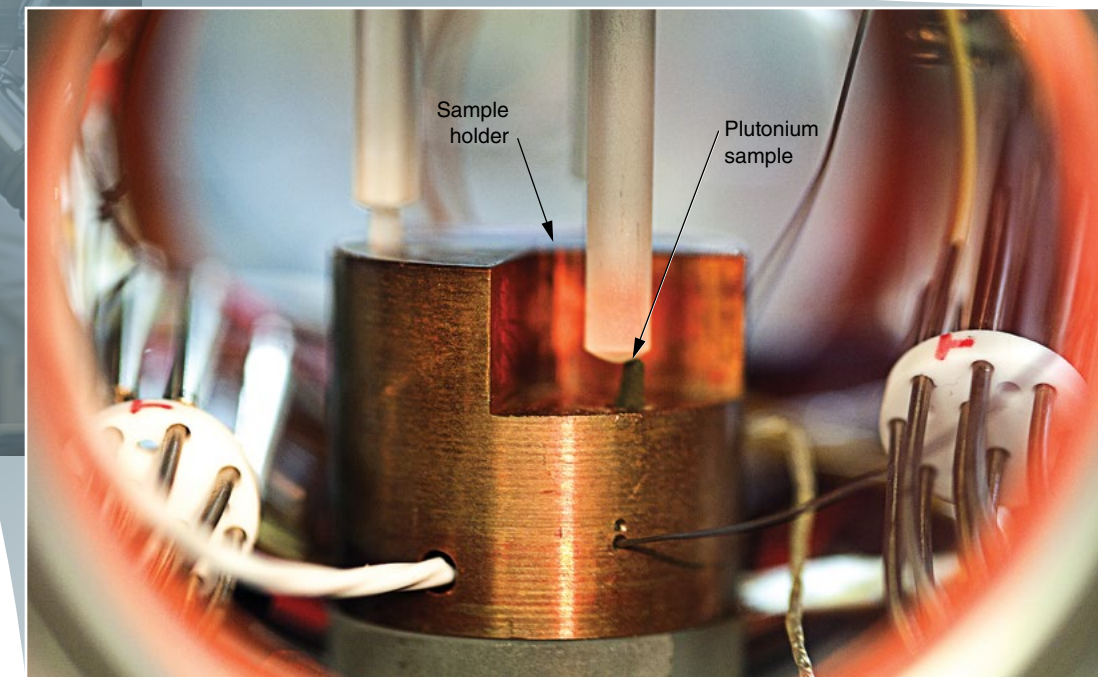
Since the end of nuclear testing, scientists have been particularly concerned about how plutonium ages because unexpected changes in the element’s chemical structure (or phase) could compromise weapons performance. In particular, scientists worried about the damage accumulated over decades as plutonium-239 decays and self-irradiates. In response, Livermore scientists launched experiments at the Laboratory’s Superblock, a city-block-long assemblage of actinide research facilities. (Complementary efforts were conducted at Los Alamos National Laboratory.) The ongoing experiments involve samples of plutonium-239 taken from old weapons and from plutonium-239 artificially aged to 200 equivalent years at present. The tests showed no significant changes in pertinent physical properties

such as density and strength. As a result, scientists determined the minimum lifetime for plutonium in existing weapons is at least 85 years. (See *S&TR*, December 2012, pp. 11–14.)

Chemist Pat Allen, the enhanced surveillance deputy program leader who also leads plutonium aging studies, notes that Livermore researchers have gained a tremendous amount of knowledge about the aging mechanisms of both uranium and plutonium as well as their static properties. However, “We have to better understand the behavior of plutonium under dynamic conditions, which is a real challenge,” says Allen. He points to a recent series of plutonium experiments at NIF conducted under a regime of extreme pressures and temperatures that are beginning to yield significant new data.

Dynamic plutonium experiments also continue at two facilities located at the Nevada National Security Site. At the underground U1a complex, chemical high explosives (HEs) are detonated next to

Samples of naturally and artificially aged plutonium, each 2 or 3 centimeters long, are measured in dilatometry experiments to check for changes in the samples’ volumes over time.



samples of plutonium-239 to obtain data on its dynamic behavior. These tests are called subcritical experiments because the configuration and quantities of explosives and special nuclear materials such as plutonium cannot create a self-sustaining nuclear chain reaction, or criticality. Subcritical experiments are thus consistent with the U.S. nuclear testing moratorium and CTBT.

Underground U1a experiments complement those conducted at the Joint Actinide Shock Physics Experimental Research (JASPER) Facility. JASPER captures data on the properties of plutonium at high shock pressures and temperatures close to those experienced in nuclear weapons. JASPER experiments

use projectiles moving at 8 kilometers per second to impact plutonium targets fabricated at the Superblock.

“We’re just beginning to understand dynamic behavior,” says Allen. The new studies are part of what he terms “Stockpile Stewardship 2.0,” an effort dedicated to understanding the dynamic behavior of both nuclear and nonnuclear materials, including those produced through new manufacturing techniques such as additive manufacturing. NIF experiments are expected to play a large role in this effort.

Long-Lasting High Explosives

One of stockpile stewardship’s most important advances has been increased

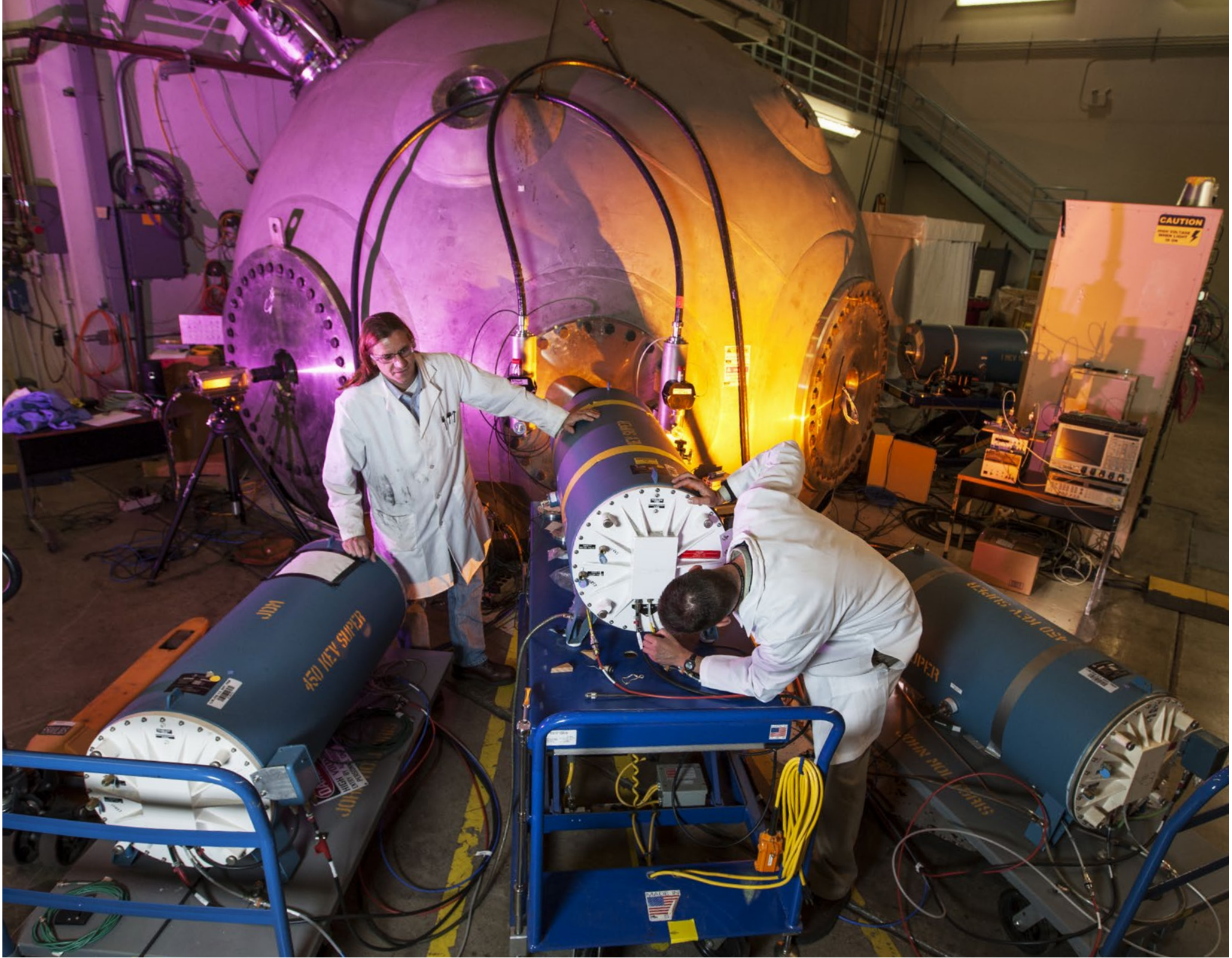
understanding of HEs. Composed of HE powder and inert plastic binder, HEs are used in the main charge, booster, and detonator of a nuclear weapon’s firing system. Jon Maienschein, director of Livermore’s Energetic Materials Center, says, “We have to understand how high explosives change over time and how these changes might affect future stockpile functionality.” He notes, however, that Livermore formulations have proven themselves extremely stable. “We expect our HEs to be long-lasting because we designed them that way,” he says, adding that surveillance activities are validating this expectation.

High-fidelity simulations mimic the extremely rapid physical and chemical detonation processes of energetic materials. They reflect accurate physical models that are used to predict likely changes in weapons’ HEs during the next one to two decades. HE computational models also allow scientists to assess data from HE and hydrodynamic tests and precisely reproduce these experiments.

“From a scientific perspective stockpile stewardship has been beneficial for developing a much deeper scientific understanding of all materials,” says Maienschein. “We’ve progressed from observing high explosives being blown up to carefully studying their chemistry, morphology, crystallinity, and aging characteristics.”

HEAF is home to some of the best-equipped HE research and testing laboratories in the world. Researchers at the facility conduct all aspects of explosives research, from synthesizing new materials to characterizing their safety and detonation properties. In 2008, NNSA named Lawrence Livermore its High Explosives R&D Center of Excellence.

Working in HEAF laboratories, Livermore chemists have developed “insensitive” HEs that are much less likely to accidentally detonate than the already safe conventional HEs used in most weapons. Insensitive HEs are remarkably



impervious to heat, shock, and impact, including from small arms fire. A new Livermore HE formulation, LX-21, is based on the Laboratory-developed HE molecule LLM-105, and has proven notably insensitive in advanced testing.

HEAF research complements experiments at CFF involving up to 60 kilograms of HE. The world’s largest indoor firing facility, CFF capabilities include high-resolution imaging and velocity measurements of detonating

nonnuclear weapons assemblies. These hydrodynamic tests create temperatures and pressures so great that solids behave like liquids. CFF’s sister facility, the Dual- Axis Radiographic Hydrodynamic Test (DARHT) Facility, is located at Los

Alamos National Laboratory. It uses two large x-ray machines instead of one to record interior images of materials and fashion them into ultrafast motion pictures of the detonation. CFF and DARHT offer complementary capabilities and are jointly

Researchers Kevin Vandersall and Joe Tringe prepare to conduct an explosives test in one of HEAF’s seven indoor firing tanks. (Photograph by George A. Kitrinos.)

used by Livermore and Los Alamos for conducting hydrotests.

Extending Weapons’ Lives
A vital element of stockpile stewardship, life-extension programs (LEPs) address weapons issues discovered through routine surveillance and annual stockpile assessments, such as aging effects that could lead to future performance degradation. Depending on the nature of these changes, parts may need to be replaced or refurbished to meet safety, security, and reliability requirements. In this way, LEPs can extend the weapons’ lifetimes for an additional 20 to 30 years without the need to conduct underground nuclear tests.

NNSA national security laboratories design the parts required for LEPs and certify the life-extended weapons when they enter the stockpile. Currently, Livermore has been assigned an LEP for the W78/88-1, a system to be interoperable between Air Force and Navy missile systems. However, the effort is currently paused to accelerate the W80 LEP in support of the U.S. Air Force Long-Range Standoff missile.

Engineer Hank O’Brien, W78/88-1 LEP program manager, recounts that at the start of stockpile stewardship, scientists and engineers did not envision LEPs. “The focus of stockpile stewards was on building new experimental and computational resources and increasing our scientific knowledge,” says O’Brien. “A few years later it became apparent we needed to perform work on the W87, and so we started thinking of life-extension programs.” The W87 LEP took about 10 years to complete. The W78/88-1 LEP will take about 20 years from start to finish.

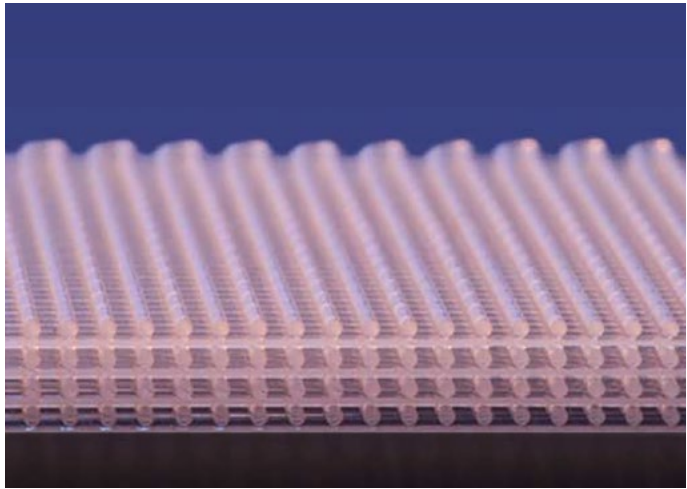
Weapons manufacturing processes are currently five decades old, and sustaining

these legacy processes for producing LEP components is an increasing challenge. Many of the original materials and methods are no longer used because of environmental and health considerations. According to O’Brien, Livermore stockpile stewards search for ways to manufacture replacement components that are less expensive, more environmentally friendly, and simpler to certify. One promising new technique is additive manufacturing, in which materials such as a polymer or metal are added layer by layer to produce objects with complex shapes and desirable material properties. (See *S&TR*, January/February 2015, pp. 4–11.) “With additive manufacturing, we can design our own material,” says O’Brien. “We can pick the density of a plastic cushion or dictate the stiffness of a metal.”

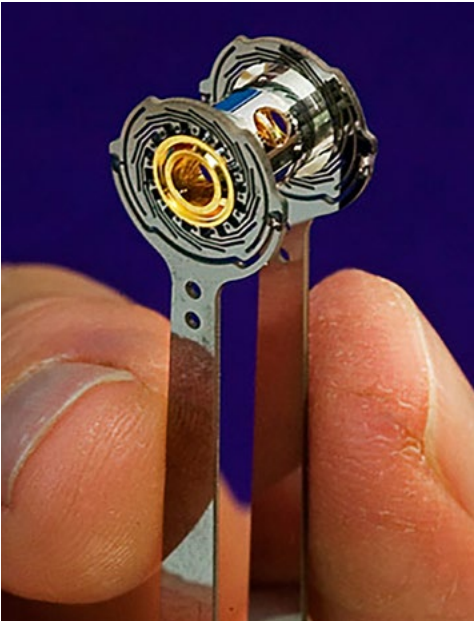
Re-Creating the Sun’s Temperatures

In the post-test era, scientists must rely on alternative methods for measuring the dynamic properties of weapons materials. The 192-beam NIF, the most energetic laser in the world, is stockpile stewardship’s flagship facility for high-energy-density physics experiments. NIF is capable of reaching temperatures of 100 million degrees and pressures 100 billion times that of the Earth’s atmosphere—conditions similar to

those in stars and detonating nuclear weapons. Producing these extreme high-energy-density environments is critical to validating theoretical models and simulation codes that improve understanding of weapons physics. NIF experiments have provided invaluable data about materials properties at regimes otherwise inaccessible in the absence of nuclear testing. Key material properties data include equation of state and material strength. “NIF has been phenomenally useful,” says physicist Desmond Pilkington, program director for Weapon Physics and Design. During the past two years scientists have made significant progress toward realizing ignition and energy gain on NIF, which is relevant to understanding thermonuclear processes in weapons. Pilkington says, “Achieving ignition will move our research to the next energy phase, but it is not the only goal. NIF will continue to open up many more doors to scientific discovery for stockpile stewardship.” Equipped with approximately 70 optical, x-ray, and nuclear diagnostics, the giant laser also helps address questions regarding design options being considered in LEPs. Changes to weapons systems through LEPs can have unintended consequences. Together with computational models, NIF experiments



Life-extension programs necessitate the adoption of new manufacturing processes such as additive manufacturing. Livermore researchers produced a silicone cushion with programmable mechanical energy absorption properties through a three-dimensional printing process using a silicone-based ink.



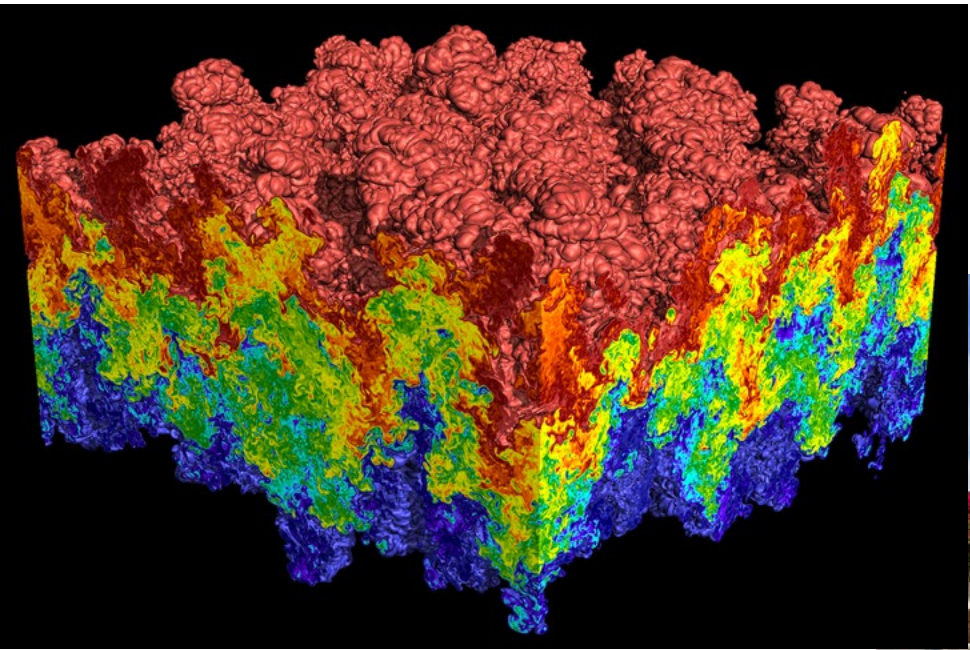
Experiments at the National Ignition Facility help scientists understand thermonuclear processes in weapons. A fully assembled ignition target incorporates a capsule assembly, hohlraum, and a surrounding thermal–mechanical package with silicon cooling “arms.”

provide valuable data for fully validating LEP concepts prior to implementation.

Surrogate Testing with Computers

When stockpile stewardship was first formulated, scientists knew that unprecedented computational capabilities were needed to integrate the vast amount of scientific knowledge of nuclear weapons processes and materials and the accumulated experimental data from hundreds of nuclear tests. The Advanced Simulation and Computing (ASC) Program (formerly known as the Accelerated Strategic Computing Initiative, or ASCI) was launched to address this need. Dedicated to improving computational power by at least a millionfold, ASC quickly became one of the most significant accomplishments of stockpile stewardship. The program has also contributed to making high-performance computing an

essential element of scientific research and spurred the U.S. high-performance computing industry. ASC simulations offer a computational surrogate for nuclear testing by accurately modeling the extraordinary complexity of nuclear weapons systems. Major advances in hardware and software have made possible a clearer understanding of the issues involved in stockpile stewardship. Full 3D, high-fidelity simulations allow physicists to observe phenomena nanosecond by nanosecond, with a level of spatial resolution and a degree of physics realism previously unobtainable. NNSA laboratories continue to house some of the world’s fastest, most powerful supercomputers, including Livermore’s 20-petaflop (quadrillion floating-point operations per second) Sequoia machine. “The calculations we run on Sequoia are incredibly involved,” says Pilkington. “Often, we find the physics is more complex than we first assumed. To understand this complexity, particularly the interaction between all aspects of a nuclear weapon, we need a high-resolution, full-system model, which requires much



larger calculations.” Most full-system simulations are still in 2D. Graduating to 3D simulations will require more powerful supercomputers. Livermore scientists are preparing for the next-generation supercomputer, Sierra, which will provide four to six times Sequoia’s sustained performance, with a peak performance speed of 120–150 petaflops. A key accomplishment of Livermore’s ASC-supported research has been the refining quantification of margins and uncertainties (QMU), an approach similar to engineering safety factors. This methodology brings together data from simulations, experiments, and theory to establish confidence factors for the key potential failure modes in weapons systems. For example, QMU helps weapons scientists rank the design options identified for LEPs. **Taking Better Care of Weapons** Mike Dunning, principal deputy for WCI, asserts that stockpile stewardship has been so successful because of the significant investments made over the past two decades in facilities, computing power, and technical expertise. However,

he cautions that the Laboratory must maintain its expertise and guard against being overly confident as weapons continue to age and stockpile stewards are called upon to enhance weapons safety and security and package weapons on new platforms. “Experiments play an essential role in providing the data to develop, improve, and ultimately validate understanding of our models,” says Dunning. “Equally important, experiments provide opportunities for our workforce to develop the judgment required to make the compromises inherent in taking a design from a computer model to something that can be engineered, built, assembled, and diagnosed. We really do and will continue to benefit from these capability investments.” Stockpile stewardship is a continuous process that requires the right tools for the job. “Nothing is wrong with the stockpile now, but we have a much smaller production complex than we used to if we need to make changes,” says Verdon. “I’m pleased that the nation is making important investments in production facilities.” He notes that a healthy complex is a crucial

Researchers used the Laboratory’s BlueGene/L supercomputer to create (left) a high-resolution simulation of turbulent thermonuclear burning in a Type 1a supernova. (bottom) The Livermore Computing Complex houses most of the Laboratory’s supercomputers. (Photograph by George A. Kitrinou.)



Finding a Balance

One of the most notable accomplishments of stockpile stewardship was a theoretical advance, namely, solving a mystery that had confounded some of the smartest physicists for five decades. Livermore physicist Omar Hurricane won the Department of Energy's prestigious E.O. Lawrence Award for leading a team that solved the mystery of missing energy produced during nuclear tests.

"The energy balance problem was first recognized in the 1960s when Livermore developed the first two-dimensional radiation hydrodynamic simulation tools. Over many decades when those tools were applied to conducted nuclear tests, it appeared that the tests violated a basic principle of physics known to every college freshman physics student: conservation of energy," says Hurricane. Many scientists had their own hypotheses about the missing energy, and all sorts of arguments raged, but the issue was never resolved. "It was something weapons designers needed to be aware of but didn't have time to address because they were fighting the Cold War," he says. "Back then, solving energy balance was less important because weapons designers could always conduct an underground nuclear test and see to what degree the principle was violated. The test data would then be folded into their codes. The entire Cold War was fought with that gap in understanding. The tests usually worked, but the issue still nagged at people because of the potential problems if you got the energy balance wrong."

When underground testing ended in 1992, solving the energy balance mystery became important because weapons designers could no longer rely on new test data to validate their codes. Starting in the early 2000s, Hurricane began leading a decade-long scientific effort to find the missing energy. "We got to the bottom of why we had a discrepancy between the results from our models and test results," he says. "Most of the components of the solution had been hypothesized previously by designers. However, a novel part crossed many disciplinary boundaries, which is why it evaded solution for so long."

Hurricane says that without the team's solution, scientists would be less certain whether changes made to the stockpile would affect the energy balance. "We are more confident executing life-extension programs and using new processes and materials. Stockpile stewardship would be much different today without this solution."

component of sustaining the nation's nuclear deterrent and provides a hedge against technological surprise.

Pilkington observes that the enduring stockpile "is a testament to the people who designed the weapons." One of the major concerns of stockpile stewardship architects was preserving the core intellectual and technical competencies of the weapons laboratories. As Pilkington notes, "People, not models, make decisions and certify LEPs."

Retaining the skills, knowledge, and abilities of stockpile stewards is paramount. "Weapons designers used to receive critical experience by performing underground tests," says Verdon. "Now, they are obtaining similar experience working on experiments at NIF, CFF, and other NNSA

facilities. Physicists and engineers still have to work together and make judgments with incomplete information, just like they did during nuclear testing." He adds that Livermore people working on LEPs also gain valuable real-world experience by collaborating with NNSA production plants on LEP components.

Verdon also notes that the stockpile stewardship "methodology" has resulted in greater ability and confidence in computational design and testing. These advances have led to tighter design cycles for new conventional weapons systems such as the low-collateral-damage bomb called BLU-129/B. (See *S&TR*, March 2013, pp. 4–9.) He says, "We developed BLU-129B on a much shorter timescale than had ever been accomplished with previous

munitions." A prototype was designed and virtually tested using advanced computational techniques. Computers then guided researchers to select the most stressing experiments to validate the design.

In the 20 years since it was established, the Stockpile Stewardship and Management Program has developed highly effective capabilities for maintaining confidence in the U.S. nuclear deterrent. In 2012, NNSA commemorated the 20th anniversary of the last U.S. nuclear explosives test and the success of the Stockpile Stewardship and Management Program, noting that the United States has no plans to conduct such tests in the future.

Stockpile stewardship is not without risk as weapons continue to age and national security requirements change. However, it has proven itself as the best approach to ensuring a safe, secure, and effective nuclear stockpile as long as nuclear weapons exist. "I believe we are taking better care of these weapons today than when we were conducting nuclear tests," says Goodwin. "We have developed a greater understanding of the way nuclear weapons work because we could not test them."

—Arnie Heller

Key Words: Advanced Simulation and Computing (ASC), Confined Large Optical Scintillator Screen and Imaging System (CoLOSSIS), Comprehensive Nuclear-Test-Ban Treaty (CTBT), Contained Firing Facility (CFF), Dual-Axis Radiographic Hydrodynamic Test (DARHT) Facility, Energetic Materials Center, energy balance, High Explosives Applications Facility (HEAF), Joint Actinide Shock Physics Experimental Research (JASPER) Facility, life-extension program (LEP), LLM-105, LX-21, National Ignition Facility (NIF), National Nuclear Security Administration (NNSA), Nevada National Security Site, plutonium-239, Sequoia, Sierra, Stockpile Stewardship and Management Program, U1A complex, W78/88-1.

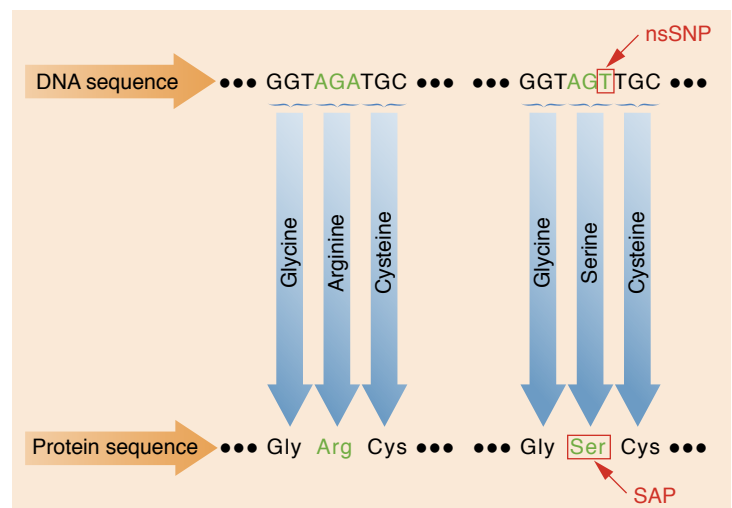
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A New Role for Hair in Human Identification

INVESTIGATORS use an assortment of forensic techniques to help identify the perpetrator or victim of a crime, but none are presently considered as reliable as DNA profiling. Only DNA analysis underwent rigorous scientific validation before entering into use by forensic scientists for law enforcement. Moreover, other forensic approaches, such as facial recognition and bite mark, hair, and fingerprint analysis, rely on a specialist to assess how well the evidence matches an image or records in a database, which introduces the risk of human error. A 2009 National Research Council assessment of forensic science detailed the weaknesses of these techniques and reported an urgent need for new science-based methods for human identification that complement DNA analysis.

“Nuclear DNA is the gold standard, but it is quite fragile,” says Brad Hart, director of Lawrence Livermore’s Forensic Science Center. “When the DNA molecule degrades from light, moisture, or heat exposure, it becomes useless for identification.” Even when deterioration is not a factor, some crime scenes—and disaster sites—lack biological material in sufficient quantities or of the right type for DNA analysis. When biological evidence exists but DNA profiling is infeasible, protein analysis could provide a solid forensic alternative.

Proteins are chemically more robust than nuclear DNA and can be found in different tissue types, including hair, shed



This illustration shows a type of genetic code variation called a nonsynonymous single nucleotide polymorphism (nsSNP) and the corresponding altered amino acid in the protein coded by that DNA, called a single amino acid polymorphism (SAP). Forensic scientists can use SAPs (and by extension, nsSNPs) to create an identification profile from protein-bearing tissue samples, such as human hair.

skin cells, bones, and teeth. Livermore forensic scientists and bioinformaticists have teamed up with researchers from Protein-Based Identification Technologies, LLC, to develop the first-ever biological identification method that exploits the information encoded in proteins. Subsequent collaboration with researchers at the University of Utah, Montana State University, University of Bradford, the University of California at Davis, University of Washington, and Utah Valley University supported and provided validation for the approach. The effort aims to identify a person using proteins extracted from a single human hair.

Common Mutations, Uncommon Approach

The new forensic technique looks at genetic mutations through the lens of protein expression. Proteins are long molecular chains formed from amino acids—the 20 basic building blocks of life. DNA is the template the body uses to make proteins. “For a DNA mutation to be reflected in a protein’s amino acid sequence, two things must happen,” explains biotechnology researcher Glendon Parker, founder of the startup company Protein-Based Identification Technologies. “Firstly, the DNA sequence must actually be expressed in a protein. Surprisingly, only one percent of the genetic code actually codes for proteins. Secondly, the mutation cannot be silent, which occurs when two different DNA sequences generate the same amino acid. A tremendous amount of variation exists in humans, so even accounting for these requirements, we still have many candidates to consider.” A DNA mutation that causes a protein to have a different amino acid sequence is called a nonsynonymous single nucleotide polymorphism (nsSNP). The corresponding altered amino acid is a single amino acid polymorphism (SAP).

With support from the Department of Defense, the multi-institutional team has been developing a database of common SAPs—those that appear with one percent or greater frequency in a population—found in human hair samples that can be used to identify a person. Hair currently has limited forensic utility because it lacks nuclear DNA. Within the 400 different proteins the researchers have reliably detected in hair, they have pinpointed 1,700 common locations for mutations and mapped SAPs and corresponding nsSNP variants for 83 of them.

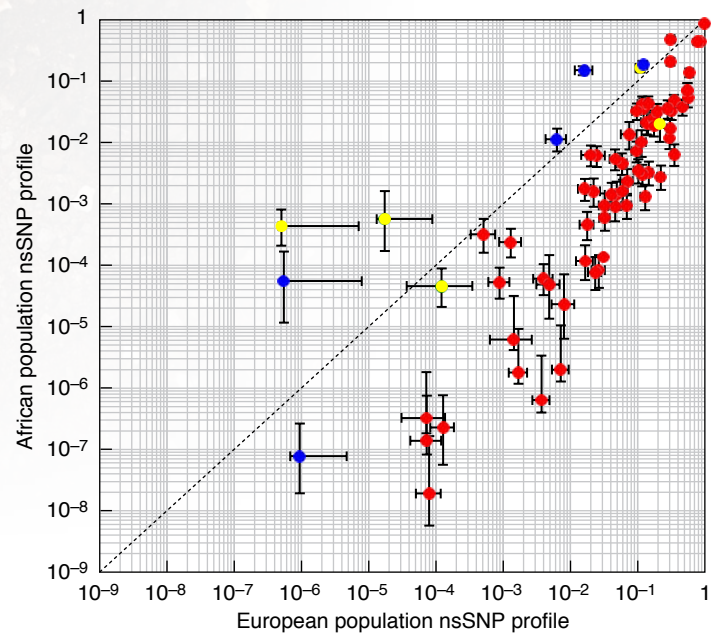
Using this data, the team can perform protein-based identification. The proteins are first extracted from a hair sample and broken down into shorter amino acid chains, called peptides. The researchers then use liquid chromatograph–mass spectrometry (LC-MS) to separate, detect, and quantify the peptide sequences. Results are compared to a sequence database to identify known SAPs present in the sample. Given data on the frequencies of each corresponding nsSNP, the researchers can estimate the power of discrimination for the protein profile. This number increases as more nsSNPs are identified. Livermore’s newly acquired

LC-MS machine has given the team’s work a significant boost. Livermore MS expert Deon Anex notes, “Our state-of-the-art mass spectrometry instrument increases the power of discrimination by two orders of magnitude. We can identify more variants, and we can also obtain the needed information with a tenth the sample size.”

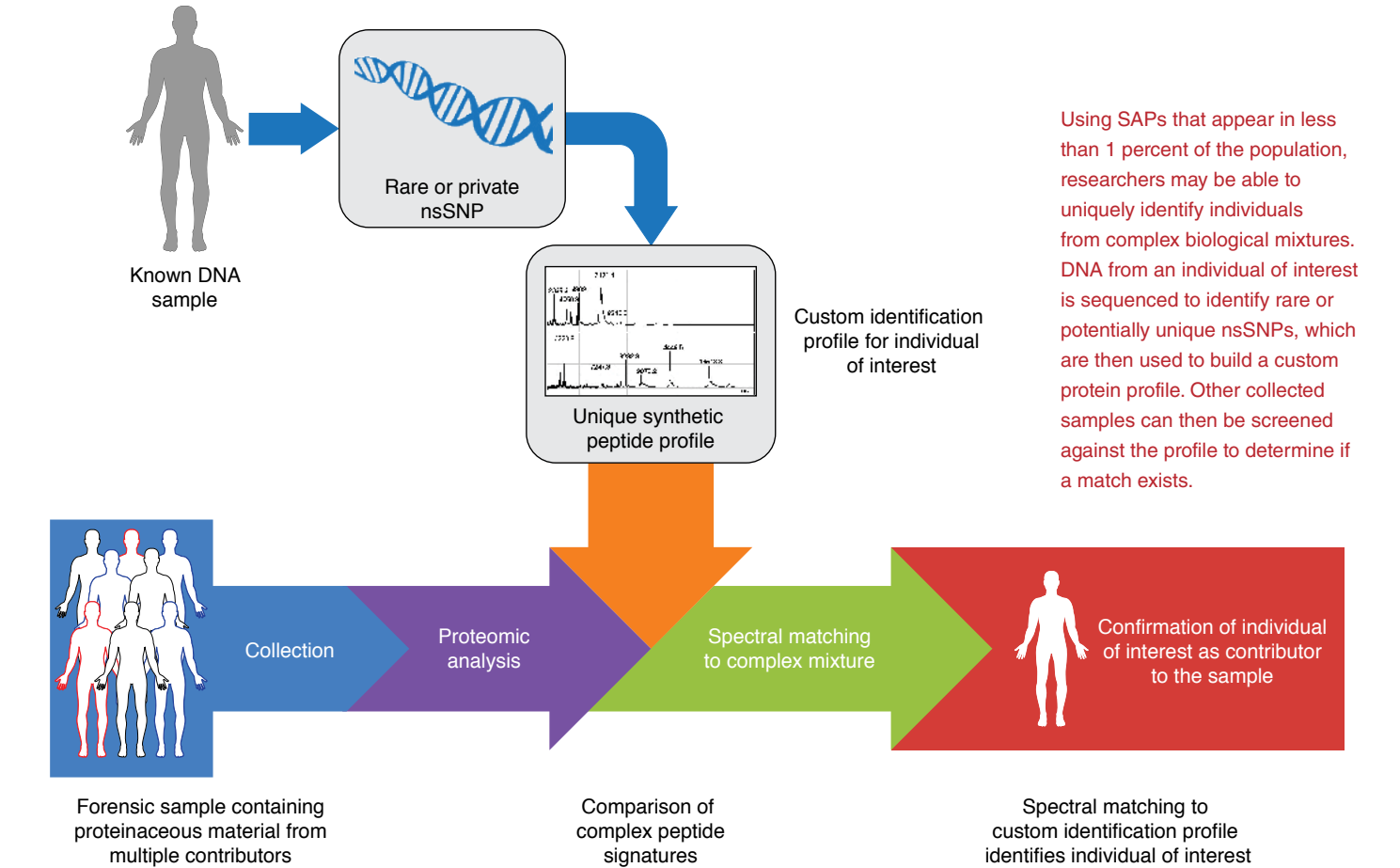
Large-scale events such as human migrations and genetic bottlenecks affect the frequency with which various mutations occur in a population. As a result, the team can also use SAP and nsSNP information to calculate the likely population background of the person who provided a sample. The researchers have tested their approach on European and African genetic pools and plan to expand their database to other genetic groups. This information benefits not only crime solvers but also archeologists. In fact, the researchers have found that they can still reliably discern SAPs and populations of origin from hairs found in 150- to 250-year-old London graves.

Upping the Pace of Research

The team is now investigating less common mutations that will have a higher power of discrimination. Such a capability could be useful for distinguishing individuals within complex biological mixtures, which can be difficult with DNA profiling. Identification



An individual's likely population of origin can be determined through protein-based identification. The chart shows the probability of various nsSNP profiles occurring in the European and African genetic populations. European–American subjects are marked in red, African–American subjects are yellow, and Kenyan subjects are blue. The dotted line denotes an equal probability of a profile being part of the European and African populations.



using rare SAPs rather than common SAPs requires a more labor-intensive workflow. The forensic scientist first sequences the DNA of the individual of interest or one of the individual’s immediate family members and identifies rare or potentially unique nsSNPs in the sample. These nsSNPs are then used to build a custom protein profile against which collected samples can be screened to determine if a match exists. Of course, the accuracy of this method depends on determining the frequency of rare nsSNPs, an area of ongoing research by geneticists.

“This project is occurring at a timely point in genetic research,” says Hart. “Currently, 13,000 exomic sequences—the protein-encoding parts of all the genes—are available, mostly of European origin, as are nearly 1,000 genomes of European and African origin. These data sets are rather limited, especially in geographic distribution, but we are at the cusp of a genetic data explosion. By 2018, an estimated one million exomic sequences from a broad geographic distribution will be available to researchers.” Access to a vastly expanded library of exomic data will enable Hart, Parker, Anex, and their fellow scientists to quantify more precisely their method’s power of discrimination and to pinpoint new mutations.

The team has two major technical hurdles to overcome before protein-based identification enters forensic use. First, the

researchers must further reduce the minimum sample size needed for analysis. Toward this end, they are optimizing protein extraction to ultimately perform identification using just a single human hair. Second, the team has to conduct a statistical analysis on peptides to verify the accuracy of the methods used for calculating the power of discrimination, as these probability estimates presuppose that an SAP in one location is not related to a mutation elsewhere in the protein sequence.

From identifying disaster victims to aiding authorities in catching murderers, protein-based profiling could be a boon to forensic scientists and the broader law-enforcement community. “Twenty-five years ago,” says Hart, “DNA identification was in the same place that protein identification is today. This method will be a game changer for forensics, but first we need to prove it.”

—Rose Hansen

Key Words: amino acid, exomic sequence, forensic science, Forensic Science Center, genetic research, liquid chromatograph–mass spectrometry (LC-MS), nonsynonymous single nucleotide polymorphism (nsSNP), nuclear DNA, peptide, protein, single amino acid polymorphism (SAP).

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The Rise of the SuperTruck

TRACTOR–TRAILER semitrucks burn 36 billion gallons of fuel annually—11 to 12 percent of the U.S.’s total petroleum consumption. In addition, each truck expends more than 50 percent of its usable propulsion energy to overcome aerodynamic resistance at highway speeds. In 1997, the Department of Energy (DOE) established the Heavy Vehicle Aerodynamic Drag Consortium to examine ways to make heavy trucks more aerodynamic, reducing air resistance (or drag) to increase their fuel efficiency. The consortium included Livermore researchers, collaborators at academic institutions such as the University of Southern California and the California Institute of Technology, industry partners, and the NASA Ames Research Center (NASA Ames).

Livermore’s work on creating more aerodynamic tractor–trailers is funded by DOE’s Office of Energy Efficiency and Renewable Energy through the Vehicle Technology Office. At the start of the consortium, the scope of the project—then led by the Laboratory’s Rose McCallen—focused primarily on altering the design of

existing trucks. (See *S&TR*, May 2003, pp. 25–28.) “We needed to understand the key areas of resistance and drag on the vehicle to make technological improvements,” says Kambiz Salari, who began leading the project with researcher Jason Ortega in 2007.

Nearly 20 years after the project began, the collaborative effort has resulted in the development of drag-reducing technologies that can be retrofitted to existing semitrucks. Such devices are already helping U.S. fleets realize fuel economy improvement (FEI). Building on this success, Livermore has shifted its research approach toward the design of a highly aerodynamic integrated tractor–trailer for DOE’s SuperTruck initiative, which aims to develop tractor–trailers that are 50 percent more efficient than conventional models.

Identifying a Need

Through computational airflow simulations produced on the Laboratory’s high-performance computing (HPC) systems and experiments conducted at NASA Ames’ wind-tunnel facilities,

Livermore researchers found that a semitruck’s underbody, back end, and gap between the tractor and trailer produce the most drag. Subsequently, the team designed, simulated, and tested add-on devices that could make the vehicles more aerodynamic. Pairs of flat panels, called skirts, attach to either side of the trailer to shorten the gap between the trailer and the ground, reducing air currents along its sides and underside. A tail device fastens to the trailer’s rear edges and extends at an angle to lessen the vehicle’s wake. Finally, a gap panel fills the space between the tractor and trailer to prevent airflow inside the void. The Livermore team has garnered several patents and records of inventions for these devices, which are manufactured by industry partners based on Livermore design recommendations.

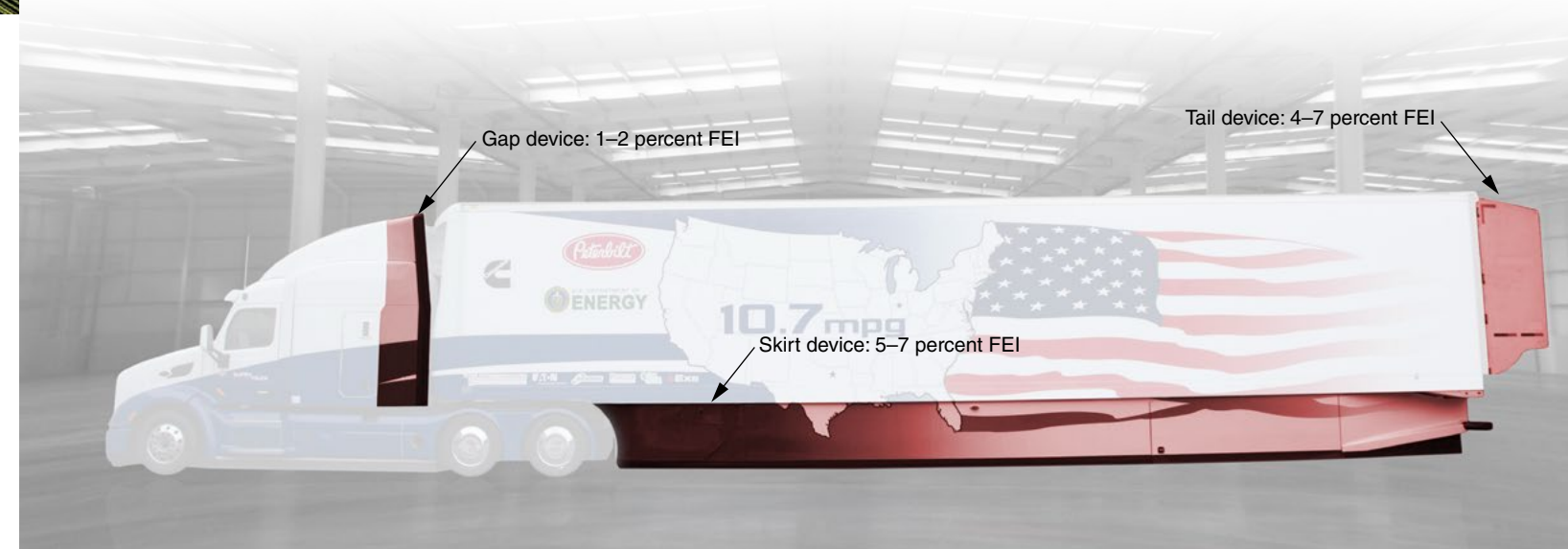
According to a 2014 Fleet Fuel Study conducted by the North American Council for Freight Efficiency, industry trends indicate that U.S. fleets are increasing their adoption rate of FEI products and technologies. The study included 11 fleets, each of which had adopted at least one drag-reduction device. If the entire U.S. fleet implemented these add-on technologies, fuel consumption could be reduced by 15 percent, which translates to 5.1 billion gallons of diesel fuel saved annually. Carbon dioxide emissions also would be reduced by approximately 52 million tons per year. Salari estimates total cost savings at nearly \$21 million annually. If gas prices fluctuate around \$3 per gallon, fuel savings for each vehicle

would offset the cost of purchasing drag-reducing devices within six months to one year.

A Two-Step Process

Proposed aerodynamic concepts are first tested on HPC systems to evaluate each device’s effectiveness under realistic road conditions. Simulations highlight the flow fields of a tractor–trailer using particle traces colored according to flow speed (shown on p. 18). If the simulation results indicate considerable fuel savings, Livermore builds a one-eighth-scale physical prototype of the device for testing at NASA Ames’ 2- by 3-meter wind tunnel. “We make approximations in our simulations,” says Ortega. “Wind-tunnel experiments and their resulting data help validate our device designs.” Salari adds, “The wind-tunnel facility is our workhorse.”

Inside the facility, researchers can reproduce air flow at highway speeds. Particle image velocimetry (PIV) is a technique that uses laser beams to measure the velocity and direction of airflow in a series of planes. Using PIV, researchers can measure the flow fields in the wind tunnel and determine flow patterns through time. If more testing is required, a full-scale wind-tunnel experiment is conducted at the NASA Ames National Full-Scale Aerodynamics Complex (NFAC), the world’s largest wind tunnel. The 24-by-36.5-meter complex is ideal for testing a full-scale



Drag-reducing devices are designed to help tractor–trailers realize fuel economy improvement (FEI). The Department of Energy’s SuperTruck demonstration vehicle is shown above with approximate FEI percentages provided by the gap, skirt, and tail devices. (Photograph of truck by Sarah Gerrity.)

tractor-trailer system, in which the trailer alone measures 16 meters. “Collaborating with NASA and applying their expertise and PIV technology to this effort has created a strong, fruitful synergy,” says Ortega. “We work with some of the best wind tunnel operators in the world.”

When a device proves promising in wind-tunnel experiments, the team then approaches manufacturers to build devices for track and road testing. These tests produce data on a device’s effectiveness and help manufacturers determine specifications for production.

More Sophisticated Models

In the early 2000s, Livermore computer scientists first modeled a generic transportation system—a simplistic design that lacked detail. As HPC advanced, algorithms became

more sophisticated, decreasing simulation time and resulting in increasingly accurate tractor-trailer models. Livermore researchers now use a more precise generic conventional model (GCM) for simulations that features truck details such as a hood, door handles, engine, wheel wells, and mirrors. GCM is unbiased—it does not favor the geometry of one manufacturer’s truck over another—and as such provides data applicable to many manufacturers.

Zachary Vane, a Ph.D. candidate at Stanford University, recently joined Livermore’s research team and is helping further the Laboratory’s computational capabilities. He is investigating advanced simulations to streamline the next-generation integrated tractor-trailer physical-testing process. The computational approach uses fewer modeling assumptions to solve Reynolds-Average Navier Stokes equations, thus providing an improved

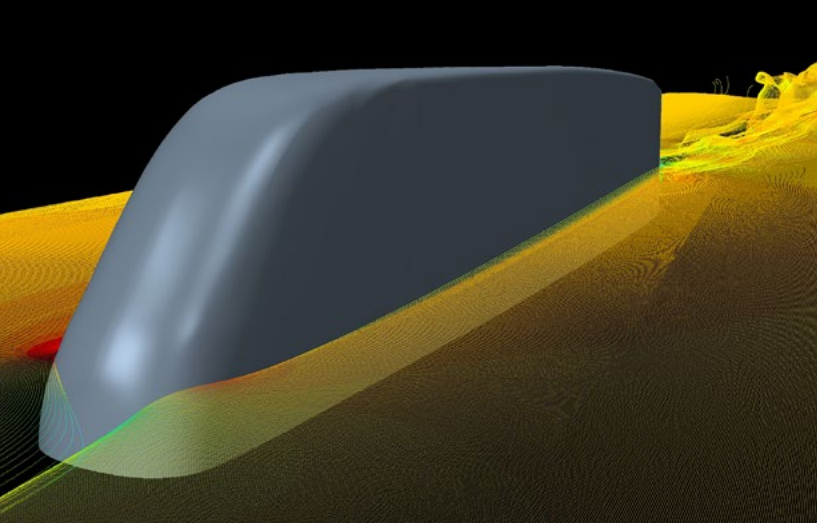
predictive capability over current computational tools. In addition, because this approach only models small-scale motions near the vehicle, it reduces high computational costs associated with other methods. This cost reduction allows the new approach to be applied to complex geometries such as an integrated tractor-trailer system. “When it comes to tractor-trailers, too many potential designs exist to physically test each one in the wind tunnel,” explains Vane. “Computer simulations, however, may allow us to narrow 100 possible experiments down to the 5 most promising designs.” With more advanced HPC systems and improved models, the team can provide higher fidelity airflow data to industry partners and more accurately recommend drag-reduction technologies to device manufacturers.

The Long Haul

Within the past two years, the Laboratory’s research has evolved from producing add-on devices to completely redesigning the tractor-trailer rig. “We can’t change much more on existing vehicles,” explains Ortega. “By installing the skirt, tail, and gap devices on semitrucks, drivers will see great fuel economy improvement. However, to significantly optimize vehicles, we need to take a different approach.” Toward this end, Livermore is developing aerodynamic specifications to benefit DOE’s SuperTruck initiative, a collaborative effort to create a next-generation highly aerodynamic integrated tractor-trailer geometry, reduce tractor-trailer weight, and improve heavy-duty engines.

Livemore’s first-generation highly aerodynamic integrated truck model, the Generic Speedform One (GSF1), was created using a one-eighth reduced-scale clay model in NASA Ames’ wind tunnel last year. “We’re thinking outside the box with the GSF1 design,” says Ortega. “Being creative makes it fun.” Initial testing for the new model involved 132 wind-tunnel experiments.

The integrated tractor-trailer structure is configured lower to the ground with a teardrop shape, enclosed wheel wells, trailer skirting, rounded trailer edges and tractor nose, and an optimized tail geometry. Though the truck still requires a gap between the tractor and trailer to allow it to turn, the gap’s size will be modified to prevent drag. The proposed GSF1 model reduces the aerodynamic drag compared to existing road vehicles by more than 65 percent. “Imagine the fuel-efficiency savings from retrofitted trucks, doubled,” explains Salari. The Livermore team plans to further refine and enhance the GSF1 shape through scaled-model wind-tunnel testing and computational optimization of surface geometry. A full-scale wind-tunnel test of an aerodynamic tractor-trailer is planned for 2016 at NFAC.



A simulation of the Generic Speedform One (GSF1) model shows flow patterns around the vehicle with particle traces colored by velocity magnitude. An integrated tractor-trailer geometry such as the GSF1 is the next step toward improving fuel efficiency for heavy vehicles.

Salari’s work in aerodynamics research recently earned him the Distinguished Achievement Award from DOE’s Vehicle Technology Office. Going forward, Salari and Ortega, along with their colleagues and collaborators, continue to look for more opportunities to improve fuel economy. As an example, Salari has proposed eliminating trailers’ corrugated sides, a feature that undermines fuel efficiency by 10 percent. Livermore will also continue research on tanker-trailer aerodynamic improvement, a market ripe with fuel-saving possibilities.

Research opportunities and the relevance of this work motivate the team. “Our research really is applicable to everyday life,” says Ortega. “It’s been extremely rewarding to see the technologies we helped develop materialize on the road.”

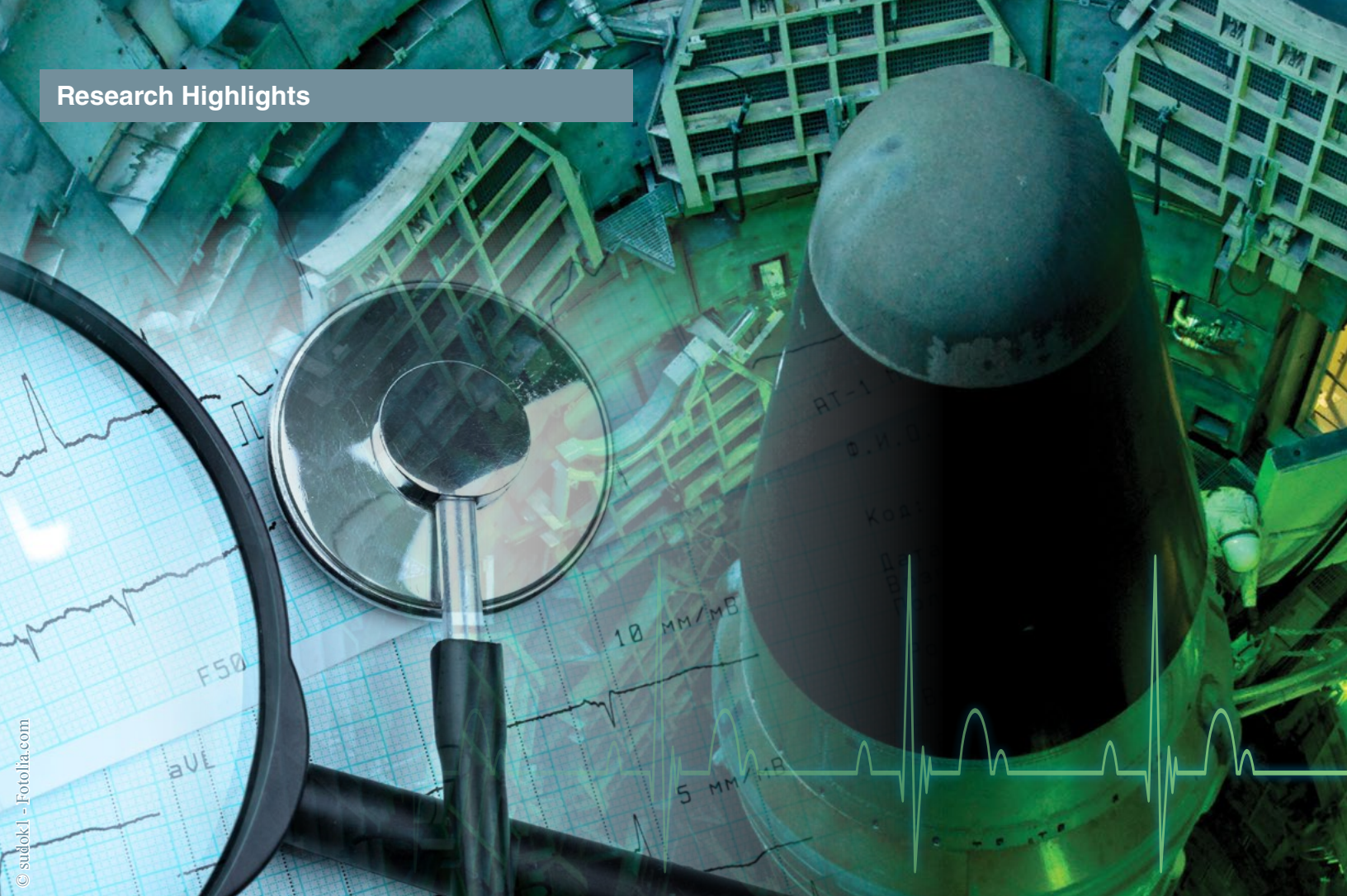
—Lanie L. Rivera

Key Words: aerodynamic truck, Department of Energy (DOE) SuperTruck initiative, drag-reducing device, fuel economy improvement (FEI), Generic Speedform One (GSF1), Heavy Vehicle Aerodynamic Drag Consortium, NASA Ames National Full-Scale Aerodynamics Complex, particle image velocimetry (PIV), semitruck, tractor-trailer.

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A tractor is suspended at the NASA Ames National Full-Scale Aerodynamics Complex (NFAC), the world's largest wind tunnel. NFAC's testing section can easily accommodate a complete tractor-trailer. NFAC has been used for full-scale performance testing of aerodynamic add-on devices. Full-scale testing of a new tractor-trailer design is planned for early 2016.





Taking the Pulse of the Stockpile

SIMILAR to how a physician orders blood tests and uses a stethoscope to assess a patient's health, scientists apply diagnostic tools to weapons systems to interrogate what lies beneath their metallic "skin." Twenty-plus years ago, before the Department of Energy (DOE) established the Stockpile Stewardship and Management Program, the primary method of evaluating a nuclear weapon's health was to essentially destroy it—the weapon was dismantled and each component tested to ensure the system's functionality.

The cessation of nuclear testing and the implementation of stockpile stewardship in the 1990s significantly changed assessment strategies for nuclear weapons. (See the article beginning on p. 6.) The Enhanced Surveillance Campaign was instituted as part of the new stewardship program in recognition

that existing weapons components need to stay in the stockpile as long as possible. Through this campaign, nondestructive diagnostic technologies have been developed that provide equivalent or better data than traditional destructive testing methods. Some of the technologies help scientists interrogate a weapon by retrieving small physical samples from the system's interior—analogueous to a patient having their blood drawn. Other technologies, such as small embedded sensors, serve as a way to continuously monitor a weapon's overall health.

Nondestructive surveillance diagnostics are integrated into all aspects of the Stockpile Stewardship and Management Program. These technologies are combined with improved materials aging models to provide data and reduce uncertainty in predicting systems performance. They also supply essential input for determining new materials that can be used to refurbish weapons systems and extend weapons lifetimes for an additional 20 to 30 years. Thus, enhanced surveillance tools help to assure the future safety and reliability of the stockpile.

Sniffing Out Material Changes

Gas composition can provide information about chemical reactions occurring in weapons materials. Such reactions can

occur between decomposition byproducts from polymers or high explosives with or without oxygen or water vapor that could leak into the sealed environment. Some of these reactions can be initiated or aggravated by the presence of ionizing radiation within the warhead.

Gaseous products such as water vapor, oxygen, and hydrogen are relatively easy to detect. Heavier organic gases are of special concern because they are less volatile yet can still diffuse throughout the system and interact with other materials. To extract gas samples from different compartments of a weapons system for analysis, scientists use a Livermore-developed microextraction technique. (See *S&TR*, July/August 2010, pp. 4–11). A narrow metal fiber coated with a polymer that adsorbs organic compounds is inserted into a weapon's headspace. The fiber is then retrieved and inserted into a gas chromatograph–mass spectrometer. The resultant spectra of the adsorbed volatile organic compounds provide a "snapshot" of a weapon's internal environment. With this technique, hundreds of compounds can be identified at concentrations down to a few parts per billion, providing insights into any changes in the weapon's polymers. When this technique was first developed in the late 1990s, sample collection was cumbersome and the samples themselves were short-lived. Improved sampling technologies have helped streamline the surveillance process and enabled long-term storage of samples for shipment to and analysis at other sites.

One of the current challenges with gas analysis is how best to analyze the resultant large spectral data sets from simple materials such as toluene to complex materials such as dodecamethylcyclhexa-siloxane. "We're turning to chemometrics to visualize these multidimensional databases and to look for correlations amongst thousands of spectra," explains Bill McLean, Livermore's Enhanced Surveillance Campaign manager. Laboratory scientists are collaborating with Professor Karl Booksh at the University of Delaware to develop chemometric visualization codes that will mine the vast chemical data sets and help scientists identify which spectral peaks are important. "Chemometric tools are very useful in extracting quantitative information and qualitative trends from complex and potentially noisy observational data. We can derive more knowledge by looking at the data in concert than by viewing changes in any single variable over time," says Booksh. With this information, researchers can determine chemical and degradation pathways and ultimately better understand the materials environment of a weapon.

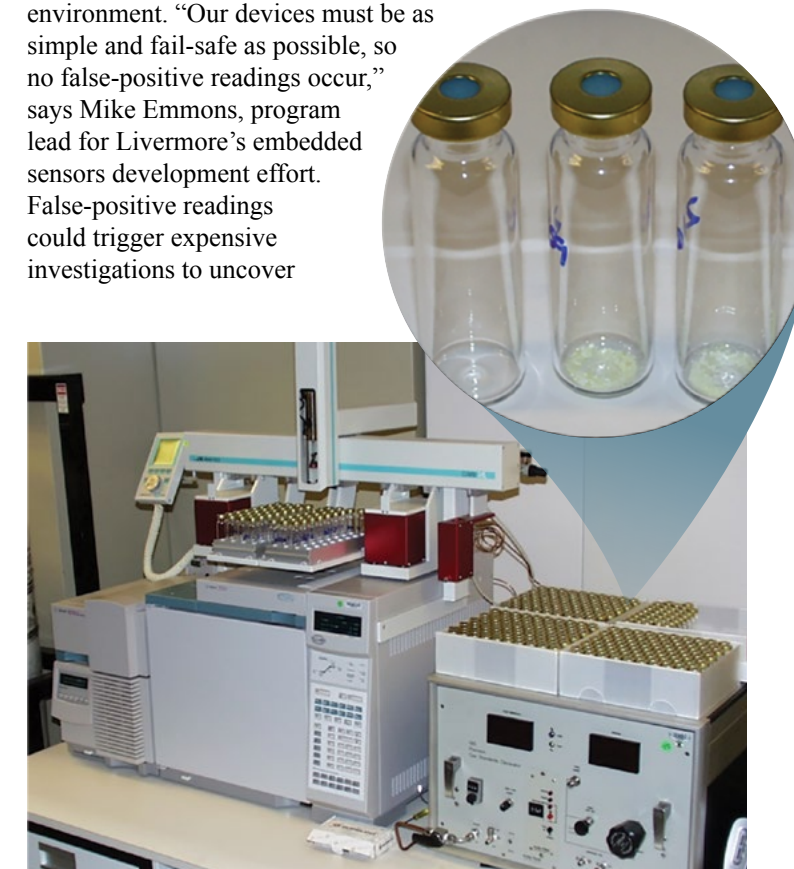
Once these pathways are understood, researchers can conduct small-scale experiments in which finger-size sealed vials of materials, or a matrix of materials, are subjected to accelerated aging with heat, radiation, and desiccation, and then sampled periodically for outgassing. In the past, whole components or entire weapons were placed into enormous ovens and

environmental chambers for accelerated aging and subsequent sampling. "In those tests," says McLean, "we did not necessarily know why something happened, or even which materials were to blame. Now, we can simultaneously test a vast array of material combinations in milligram amounts to pinpoint where problems originate. These techniques are smaller, faster, and cheaper than traditional methods."

Simple, Effective Devices

Embedded sensors provide persistent surveillance of the aging stockpile. These tiny and rugged sensors can be added into existing weapons and inserted into a system during a life-extension program. Once installed, the sensors provide continuous monitoring and nearly instantaneous detection of anomalies. (See *S&TR*, July/August 2008, pp. 12–19.)

Embedded sensors must be simple yet durable—remaining viable for thirty years within a high-radiation environment. "Our devices must be as simple and fail-safe as possible, so no false-positive readings occur," says Mike Emmons, program lead for Livermore's embedded sensors development effort. False-positive readings could trigger expensive investigations to uncover

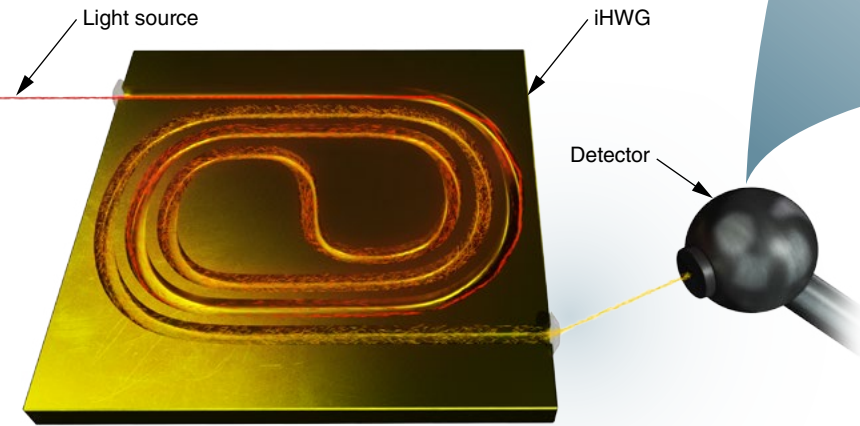


(top) Miniature sample vials are filled with combinations of potentially reactive gas compounds in small (milligram) amounts. (bottom) The vials are placed in heater blocks that are sampled periodically with a gas chromatograph–mass spectrometer equipped with an auto sampler for solid-phase microextraction.

nonexistent problems. “Whatever we do, we can’t impede the functionality of the weapon,” says Emmons. “Essentially, we are creating sensors that closely follow the ‘no mass, no volume’ dictum.” Much of the work on embedded sensors had its genesis in the Transformative Materials Initiative, an extensive three-year Laboratory Directed Research and Development project in the mid-2000s that focused on creating new multifunctional materials and sensors for long-term Laboratory mission needs.

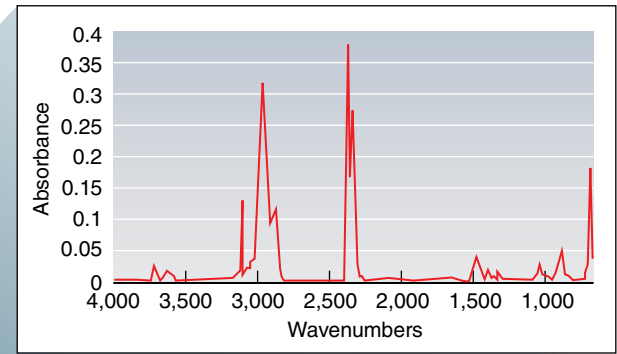
Embedded gas sensors provide data on the gas mixtures collecting in the spaces between components over time, and what chemical reactions and materials are involved. Livermore scientists are developing compact gas sensors based on Raman scattering and mid-infrared (MIR) absorption spectroscopy. In the former, laser light is transmitted via a solid-core optical fiber probe to an integrated hollow waveguide (iHWG). The laser excites gas molecules within the waveguide, producing Raman scattered light, which is transmitted via the same fiber bundle to a detection system. Similarly, MIR light from either a broadband or narrowband source is also transmitted via a solid-core optical fiber to an iHWG, where molecules absorb some of the light. The remaining unabsorbed light is transmitted back through the same fiber bundle to a detection system. Both Raman and MIR spectroscopies yield complementary spectral “fingerprints” of the gas encountered by the beams. Together, these techniques provide a broad in situ gas-sensing capability for detecting and quantifying all but the noble gases.

iHWGs are a key innovation developed by Livermore’s Chance Carter and coworkers in collaboration with Professor Boris Mizaikoff’s research group at Ulm University in Germany. An iHWG is a layered structure with light-guiding channels integrated into a rigid, solid-state material. Reflective coatings and a retro-reflector enable optical path lengths of up to approximately 1 meter in a compact size. This compactness is critical for embedded sensing in a weapon. Whereas conventional hollow waveguides of 1-meter path length require 1 meter of space, the

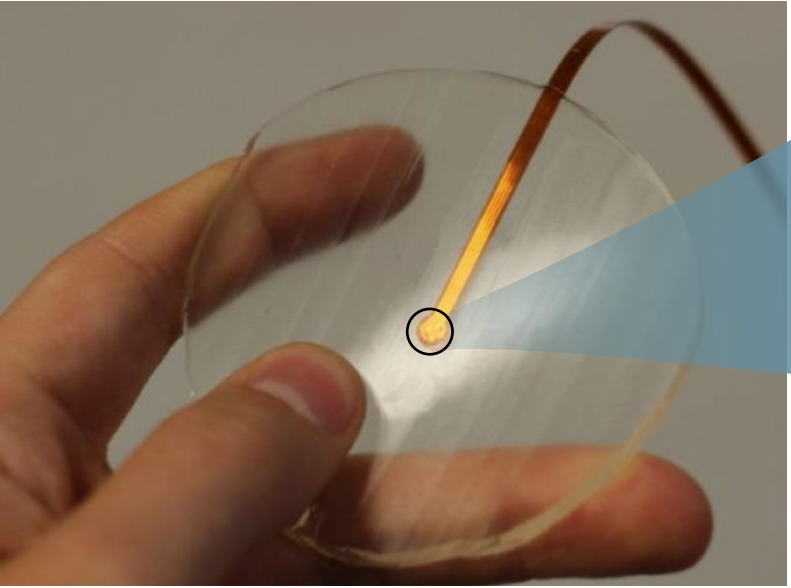


Livermore-developed iHWGs fit easily into the palm of a hand. “An iHWG essentially acts as an efficient, small-volume, miniaturized gas cell and reflective ‘light pipe’ for co-locating light with the gas,” explains Carter. “The iHWG concept represents a next-generation waveguide of unprecedented small size with customizable optical path lengths.” Another advantage of these gas sensors is that they are passive in nature. Emmons notes, “We don’t have to remove samples of solid or gaseous materials or disturb the weapons system in any way to collect the data.”

Knowing the mechanical state of a weapon provides assurance that the parts and pieces are in place and mechanically stable. Several different types of embedded sensors have been developed to collect such information. Mechanical impulse sensors use tiny accelerometers to determine whether a system has been jostled or shaken, pressure sensors use optical interferometry to detect materials aging or gas leakage, and stress sensors detect the movement of parts relative to each other. For example, Livermore has designed a contact stress sensor (CSS) that is smaller than a dime to measure contact stress—or the squeezing force—between two surfaces. Based on microelectromechanical systems, these devices are ideal for embedding because of their small dimensions, material properties, low power consumption, and mass



The integrated hollow waveguide (iHWG) is a gas cell that is built as an optical waveguide, enabling the effective optical path length to be much longer than the physical size of the device. In operation, for both infrared- (IR-) and Raman-based embedded sensors, an optical fiber delivers light from an external source located outside the weapon to the embedded iHWG. The light then interacts with gases that have diffused into the iHWG from the weapon’s atmosphere. The resulting Raman scatter and IR attenuated light are collected via another optical fiber and transmitted to an external detection system for analysis. (Rendering by Kwei-Yu Chu.)



The Livermore-developed contact stress sensor is smaller than a dime and measures changes in pressure at the interface between two materials using an extremely small, thin silicon diaphragm. Any changes in pressure alter the silicon’s electrical resistance, which can be measured with a piezoresistor at the end of the diaphragm.

manufacturability. CSS employs an extremely small, thin silicon diaphragm. Any changes in pressure alter the silicon’s electrical resistance, which can be measured with a piezoresistor at the end of the diaphragm. Otherwise, the diaphragm is inert, springing back to its original shape when pressure is removed. “This sensor is so thin and small, it does not perturb the load we want to measure,” says Emmons.

A spin-off device, the optical force probe, also uses a silicon-based pressure-sensitive diaphragm, but with an added twist. An optical fiber stretches across the diaphragm and is pressed down when the diaphragm bends under load. “By shining a light into the weapon, we can measure how much the fiber is stretched and correlate the measurement to the strain and interface loading in that area of the system,” explains Emmons. A third mechanical sensor takes its cue from recent iButton technology. “We are working off the same concept, namely, a very small, battery-powered, durable sensor that can stick to something and later download recorded data,” says Emmons. “In our case, we are designing a logger for monitoring shock and vibration.” If jolted, a small accelerometer in the embedded logger would be triggered, recording the motion.

To extract data from embedded sensors, researchers have developed a portable diagnostics unit that can download sensor data and provide the necessary power sources, lasers, and data-acquisition hardware. Retrieving the data is as simple as attaching the diagnostics unit to a warhead.

Building a Foundation

An important part of sensor development is introducing these technologies to the weapons community early, so that scientists can see the devices’ relevance and compatibility with their goals and

efforts. Emmons says, “We try to incorporate various sensors into compatibility materials tests, hydrotests, engineering tests, and any other test in which they could be useful in gathering data. These tests provide a better foundation for their use in weapons systems.”

Researchers are also investigating how to make the sensors more widely available outside the weapons complex. The CSS technology, for instance, has been licensed to MicroMetrics, Inc., which is using it to build sensors for personal devices, industrial products, and sporting goods. Sensors have also been installed into soldiers’ helmets—if a blast occurs, the sensor data indicates to physicians how much pressure was created by the blast and, consequently, how badly a soldier might be injured.

Meanwhile, surveillance continues to be a vital part of assessing the state of the U.S. nuclear arsenal. Advanced nondestructive diagnostics developed through Livermore’s Enhanced Surveillance Campaign are dramatically improving the nation’s ability to conduct surveillance activities in ways that are robust, scientifically defensible, and cost effective. Moving forward, the search continues to find ever more sensitive tools and advanced technologies for assessing the health of the stockpile.

—Ann Parker

Key Words: chemometrics, contact stress sensor (CSS), embedded logger, embedded sensor, Enhanced Surveillance Campaign, integrated hollow fiber waveguide (iHWG), nondestructive surveillance, nuclear stockpile, optical force probe, outgassing, Raman spectroscopy, shock/vibration logger, Stockpile Stewardship and Management Program.

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In this section, we list recent patents issued to and awards received by Laboratory employees. Our goal is to showcase the distinguished scientific and technical achievements of our employees as well as to indicate the scale and scope of the work done at the Laboratory. For the full text of a patent, enter the seven-digit number in the search box at the U.S. Patent and Trademark Office’s website (<http://www.uspto.gov>).

Patents

Microfluidic Ultrasonic Particle Separators with Engineered Node Locations and Geometries
Klint A. Rose, Karl A. Fisher, Douglas A. Wajda, Raymond P. Mariella, Jr., Christopher Bailey, Dietrich Dehlinger, Maxim Shusteff, Byoungsok Jung, Kevin D. Ness
U.S. 8,991,614 B2
March 31, 2015

Catalyst Functionalized Buffer Sorbent Pebbles for Rapid Separation of Carbon Dioxide from Gas Mixtures
Roger D. Aines
U.S. 8,992,845 B2
March 31, 2015

Measurement of Wave-Front Aberration in a Small Telescope Remote Imaging System Using Scene-Based Wave-Front Sensing
Lisa A Poyneer, Brian J. Bauman
U.S. 8,995,787 B2
March 31, 2015

Liquid and Gel Electrodes for Transverse Free Flow Electrophoresis
Byoungsok Jung, Klint A. Rose, Maxim Shusteff, Alexandre Persat, Juan Santiago
U.S. 8,999,129 B2
April 7, 2015

Monodisperse Microdroplet Generation and Stopping without Coalescence
Neil Reginald Beer
U.S. 9,011,777 B2
April 21, 2015

Ultrafast Chirped Optical Waveform Recorder Using a Time Microscope
Corey Vincent Bennett
U.S. 9,013,705 B2
April 21, 2015

Method of Concurrently Filtering Particles and Collecting Gases
Mark A. Mitchell, Annemarie Meike, Brian L. Anderson
U.S. 9,017,458 B2
April 28, 2015

System for Controlling Apnea
John F. Holzrichter
U.S. Patent 9,022,032 B2
May 5, 2015

Anti-Clogging Filter System
Erik P. Brown
U.S. 9,034,066 B2
May 19, 2015

Micro-Fluidic Partitioning between Polymeric Sheets for Chemical Amplification and Processing
Brian L. Anderson
U.S. 9,038,689 B2
May 26, 2015

Shape Memory Polymer Foams for Endovascular Therapies
Thomas S. Wilson, Duncan J. Maitland
U.S. 9,039,733 B2
May 26, 2015

Protection of Porous Carbon Fuel Particles from Boudouard Corrosion
John F. Cooper
U.S. 9,040,205 B2
May 26, 2015

Method for Chemical Amplification Based on Fluid Partitioning in an Immiscible Liquid
Brian L. Anderson, Bill W. Colston, Christopher J. Elkin
U.S. RE45,539 E
June 2, 2015 (Reissued date)

Shape Memory Polymers
Thomas S. Wilson, Jane P. Bearinger
U.S. 9,051,411 B2
June 9, 2015

System for Autonomous Monitoring of Bioagents
Richard G. Langlois, Fred P. Milanovich, Billy W. Colston, Jr., Steve B. Brown, Don A. Masquelier, Raymond P. Mariella, Jr., Kodomudi Venkateswaran
U.S. 9,052,255 B2
June 9, 2015

Nanodevices for Generating Power from Molecules and Batteryless Sensing
Yinmin Wang, Xianying Wang, Alex V. Hamza
U.S. 9,052,283 B2
June 9, 2015

Awards

Nerine Cherepy was selected as a **senior member** of the **Institute of Electrical and Electronics Engineers** (IEEE)—the world’s largest professional association dedicated to advancing technological innovation and excellence. Only 7 percent of IEEE members attain the level of senior member, which requires at least 10 years of professional experience and significant contributions, achievements, publications, and course development or technical direction in IEEE-designated fields. Cherepy’s most notable contributions have been in the field of radiation detectors and detection materials. She and her team have discovered two new scintillator materials with breakthrough performance for gamma-ray spectroscopy.

Department of Energy (DOE) Secretary Ernest Moniz has awarded six Lawrence Livermore scientists with **DOE Secretarial Honor Awards**. This award is the department’s highest form of nonmonetary employee recognition and is bestowed upon DOE employees for their career service and contributions to the mission of the department and to the benefit of the nation.

Livermore climate scientist **David Bader** was recognized for his leadership of the Accelerated Climate Modeling for Energy (ACME) project—a multi-institutional effort involving eight DOE national laboratories, the National Center for Atmospheric Research, four academic institutions, and one private-sector company. ACME is intended to accelerate the development and application of fully coupled, state-of-the-science Earth-system models for scientific and energy applications.

Aaron Miles and **Deborah Wojtowicz** of the Weapons Complex and Integration Principal Directorate, and **Gregory DiPeso, Dale Darling,** and **James Wolford** of the Global Security Principal Directorate, all received recognition for their participation in the Office of Intelligence and Counterintelligence Analytic Team. The Laboratory scientists were cited for their contributions to a technically challenging and high-priority Intelligence Community Assessment, the results of which will directly affect DOE and National Nuclear Security Administration policy and budgetary decisions.

Lawrence Livermore’s **Yunyan Zhang**, a climate scientist within the Laboratory’s Atmospheric, Earth, and Energy Division, has earned \$2.5 million for her research to improve the understanding of how soil moisture and surface diversity affect cloud formation and precipitation. As the recipient of the **Department of Energy Early Career Research Program**, Zhang will receive \$500,000 for five years to support her research. Zhang’s specific interests include clouds and convection, low-cloud climate feedback, aerosol indirect effect, and land–atmosphere interaction. DOE’s Early Career Research Program is designed to bolster the nation’s scientific workforce by providing support to exceptional researchers during the crucial early career years, when many scientists do their most formative work.

Lawrence Livermore researchers **Tiziana Bond** and **Jean Michel Di Nicola** were recently named **senior members** of the **Optical Society** (OSA), an international society for optics and photonics scientists, engineers, educators, and business leaders. Senior membership status recognizes members with more than 10 years of significant experience and professional accomplishments or service in their fields.

Bond is a senior engineer and capability leader in the Laboratory’s Engineering Directorate and currently works on laser modeling, image post-processing, and operation support for the National Ignition Facility (NIF) and Photon Science Principal Directorate within the Laser Modeling and Analysis Group. Her work focuses on enabling nanotechnology for small form-factor chem–bio sensors and enhanced energy harvesting and generation exploiting new areas of plasmonics, metamaterials, and surface-enhanced Raman and infrared spectroscopies. Di Nicola, a research scientist and acting group leader for the Laser Modeling and Analysis Group, works with NIF, the Advanced Radiographic Capability, and the High-Repetition-Rate Advanced Petawatt Laser System, and also develops laser codes. Di Nicola’s research expertise is in laser physics, nonlinear optics, and laser modeling of high-energy and high-peak-power lasers.

(continued from p. 2)

Unlocking the Secrets of Star Creation

On April 1, 1995, the Hubble Space Telescope captured the famous images of the “Pillars of Creation” in the Eagle Nebula. Twenty years later to the day, a team at Livermore’s National Ignition Facility (NIF) conducted the first experiment in a new campaign aimed at understanding how stars are born in these cosmic formations. The experimental series investigates the origin and dynamics of pillar formation at the boundaries of HII regions (star-forming molecular hydrogen clouds) in the presence of ablative stabilization. This process prevents the growth of traditional Rayleigh–Taylor hydrodynamic instability pillars that are well known in the context of inertial confinement fusion.

The experiment’s first shot was designed to study target debris and the performance of a three-hohlraum array. The NIF laser fired a 10-nanosecond pulse of ultraviolet light into each of the three hohlraums in sequence, and the hohlraums re-radiated the energy as a 30-nanosecond x-ray pulse. The x rays drove a shock into a layered foam and successfully created a miniature version of a pillar. The next four scheduled NIF shots focus on the “cometary model,” one of several different theories scientists have advanced to explain the physics of pillar formation. The team will study whether pillars could form from a dense cloud core, resembling the head of a comet with vaporized and shocked matter stretched out like a comet’s tail, and also whether more exotic, theorized nonlinear hydrodynamic instabilities could play a role.

NIF is the only facility that can generate an x-ray source that is sufficiently intense, long-lasting, and collimated to drive cometary flows and directional instabilities in scaled laboratory experiments and to permit assessment of models for producing flows that generate pillars. The results of the team’s research could guide new ground-based observations of molecular clouds. In addition, the team will investigate deeply nonlinear hydrodynamic instabilities in the presence of sustained, highly directional illumination. Furthermore, the NIF experiments could generate exotic instabilities that have only been theorized or seen in astrophysical simulations.

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Implantable Electrode Coating Is Good as Gold

Researchers from Lawrence Livermore and the University of California at Davis have found that covering an implantable neural electrode with nanoporous gold could eliminate the risk of scar tissue forming over the electrode’s surface. The team, which included Laboratory scientists Monika and Juergen Biener, demonstrated that the nanostructure of nanoporous gold achieves close physical coupling of neurons by maintaining a high neuron-to-astrocyte surface coverage ratio. Close physical coupling between neurons and the electrode plays a crucial role in recording fidelity of neural electrical activity. The findings were featured on the cover of the April 8, 2015, issue of the journal *Applied Materials and Interfaces*.

Neural interfaces (e.g., implantable electrodes or multiple-electrode arrays) have emerged as transformative tools to monitor and modify neural electrophysiology, both for fundamental studies of the nervous system, and to diagnose and treat neurological disorders. These interfaces require low electrical impedance to reduce background noise and close electrode–neuron coupling for enhanced recording fidelity. One main obstacle in maintaining robust neuron–electrode coupling is that scar tissue can potentially encapsulate the electrode.

Typically, low-impedance nanostructured electrode coatings rely on chemical cues from pharmaceuticals or surface-immobilized peptides to suppress scar tissue formation over the electrode surface. However, the team found that nanoporous gold, produced by an alloy corrosion process, is a promising candidate to reduce scar tissue formation. Their results show that nanoporous gold topography, not surface chemistry, reduces astrocyte surface coverage. Nanoporous gold has attracted significant interest for use in electrochemical sensors, catalytic platforms, fundamental structure–property studies at the nanoscale, and tunable drug release. Contact: Monika Biener (925) 424-6157 (biener3@llnl.gov) or Juergen Biener (925) 422-9081 (biener2@llnl.gov).

New X-Ray Microscope Poses Technical Challenges

National Ignition Facility (NIF) scientists and engineers are endeavoring to fit a three-meter-long x-ray microscope into the space between the back of the diagnostic insertion manipulator and the inner wall of the facility’s target bay. Livermore physicist Louisa Pickworth, the project’s lead scientist, explains that the new Kirkpatrick-Baez optic (KBO) diagnostic is needed to obtain high-resolution images of the “hot spots” at the center of target capsules during NIF inertial confinement fusion implosions.

The specially designed diagnostic will provide improved spatial resolution, higher imaging throughput (signal strength), and the ability to select wavelength, which is currently unavailable using standard pinhole framing camera technology. To achieve those goals, four pairs of mirrors that make up four x-ray imaging channels must be precisely aligned. In addition, the overlapping image axis of the four pairs needs to be aligned to within a 50-micrometer radius of the center of the NIF target, and the positioning must be highly repeatable between experiments.

Development of the KBO diagnostic was a collaboration between Livermore’s NIF and Photon Science Principal Directorate and the Physical and Life Sciences Directorate. To provide wavelength filtering to accommodate different experimental needs, the team developed special multilayer coatings for the KBO system’s mirrors. Extensive simulations and off-line testing of the system’s optics and other components have produced good results, showing substantial improvements in throughput and resolution over pinhole imaging systems. The first phase of the project, labeled KBO 1, is scheduled for this fall, with subsequent phases scheduled for next fiscal year.

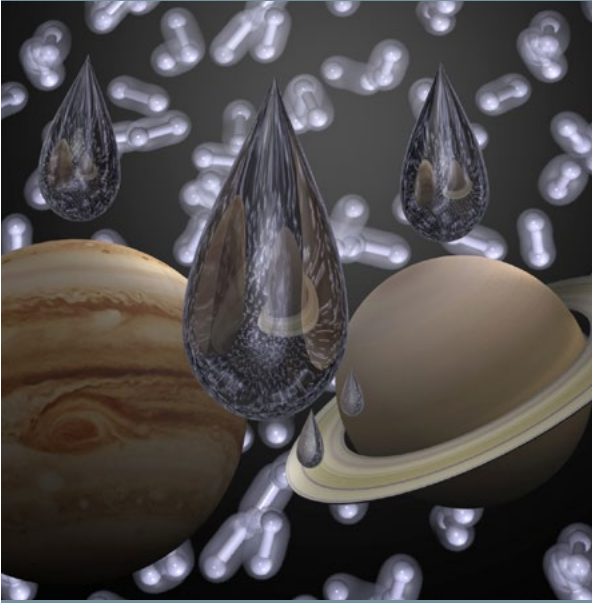
Contact: Louisa Pickworth (925) 423-1309 (pickworth1@llnl.gov).

Stockpile Stewardship at 20 Years

For more than four decades, nuclear testing had provided the means to assure confidence in the nation’s nuclear stockpile. In September 1996, President Clinton announced his decision to seek a Comprehensive Nuclear-Test-Ban Treaty and directed the Department of Energy (DOE) to take the required actions for sustaining confidence in the nuclear stockpile without nuclear testing. The resulting Stockpile Stewardship and Management Program is the ongoing effort to maintain the safety, security, and reliability of the U.S. nuclear deterrent without full-scale testing. Details of the program were arrived at following months of close consultation between the directors of the three DOE weapons laboratories (Livermore, Los Alamos, and Sandia national laboratories), DOE officials, and congressional leaders. The new approach relied on advanced scientific understanding of nuclear weapons through a combination of theoretical advances, nonnuclear (including subcritical) experiments, supercomputer simulations, and enhanced stockpile surveillance. In 2012, the National Nuclear Security Administration commemorated the 20th anniversary of the last U.S. nuclear explosives test. This year marks two decades of the highly effective and successful Stockpile Stewardship and Managment Program.

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Science on a Grand Scale



For the past decade, the Computational Grand Challenge Program has supported unclassified research efforts that expand the frontiers of science and computation.

Also in September

- Experiments reveal supercapacitor electrodes exhibit surprising behavior.
- Laser experiments that subject tantalum to extreme conditions have undermined a benchmark metallurgic theory.
- Livermore scientists uncover a gene that enables bacteria to survive in the harsh ionic liquid solvents used in producing biofuels.